MONITORING OF FISH AND FISH-FEEDING HABITS ON THE SHORELINE OF RARITAN AND SANDY HOOK BAYS, NEW JERSEY: INTERIM REPORT

A Report to the U.S. Army Engineer District, New York

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INTRODUCTION

The U.S. Army Corps of Engineers, New York District (CENAN) is planning to nourish beaches along the shoreline of Sandy Hook Bay and southern Raritan Bay, New Jersey, (Figure 1) as part of erosion control efforts. There is concern that dredging and filling operations associated with nourishment could potentially impact commercially and ecologically important coastal fish species and the infaunal macroinvertebrates they rely upon as a source of food. Impacts from nourishment operations are typically confined to the sand borrow sites and beach fill areas and can include reduced abundance or altered community structure of infauna, altered feeding habits among fish and invertebrates, and increased turbidity (National Research Council 1995). In order to assess such impacts CENAN is conducting ecological monitoring of intertidal infauna and seineable fish inhabiting the intertidal zone of three beaches in Raritan and Sandy Hook Bays (Figure 2). The results of infaunal sampling have been previously reported (Ray 2004). The present report presents initial analyses of data from the seine collections and fish feeding habits studies.

METHODS

Field Sampling

Beaches at Port Monmouth, Keansburg, and Union Beach were sampled at seven stations each (Figure 2, Table 1). A 15.2 x 1.8-m beach seine with a 1.8 x 1.8 x 1.8-m bag and 6-mm square mesh net was pulled perpendicular to the shoreline starting at a depth of approximately 1 m at each station. Seine hauls were made during daylight low tides on a monthly basis beginning in early summer and ending in late fall. Two collections were made in 2002 (September and October) and six in 2003 (June to November). Northern Ecological Associates, Inc. collected all samples with assistance from personnel from the U.S. Army Engineer Research Development Center (ERDC), and CENAN.

Seine hauls were sorted on the beach and all fishes identified to the lowest practical taxonomic level, counted, total length (TL) in mm measured and the total catch of each species weighed. Voucher specimens were archived and subsequently verified by taxonomic experts. Because it was impractical to sort large mixed catches of bay anchovy (*Anchoa mitchelli*) and striped anchovy (*A. hepsetus*) in the field, their abundances were pooled and listed as anchovy. When extremely large numbers of a particular species were collected, abundance was estimated by comparing the weight of a subsample of 50 individuals to the weight of the total catch of that species. Size frequency histograms were constructed for individual species wherever sufficient numbers of specimens were collected. A sample size of 33 specimens was considered to be the minimum necessary to accurately characterize size structure.

A HydroLab® water quality meter was deployed during each sampling period approximately 100 m offshore yielding data on salinity (ppt), temperature (^{o}C), turbidity (NTU), and dissolved oxygen concentration (mg/l). Results of these water quality measurements are reported in Ray (2004).

Fish Feeding Habits

Up to 50 specimens of select numerically dominant species encountered in each seine haul were fixed in a 4% formalin solution and shipped to ERDC. In the laboratory, fishes were measured and their stomachs dissected out and placed in 70% ethanol. Individual stomachs were subsequently opened under a dissecting microscope and the contents identified to the lowest practical identification level. The volume of each prey category was estimated using a grid-count method. Briefly stated, the gut contents were evenly spread over a Petri dish and volumes of individual prey items visually estimated. A grid-square was place under the counting chamber and the numbers of grid squares covered by each prey category counted. The contribution of the item to total gut contents was calculated as the percentage of total grid points covered by the sample. For instance, if amphipods accounted for 33 of 100 grid points covered by a sample then the contribution of amphipods to that specimen's gut contents would be 33%. Frequency of occurrence of prey items was calculated to determine if certain items were present infrequently, but in disproportionate volume compared to those consistently contributing to the diet. Wet-weight biomass of prey items was also measured. Because of the small volume of individual stomachs biomass was generally pooled over 5 mm fish size intervals. Biomass of silverside prey were pooled into two fish size classes: < 60 mm and > 60 mm to facilitate comparison with a previous study (Burlas *et al*., 2001). Mineral grains and other inert objects commonly found in the stomach contents were not recorded.

Statistical Analyses

Community species composition was analyzed by Non-Metric Dimensional Scaling (MDS) and Analysis of Similarity (ANOSIM) using PRIMER software. All species were included in the analysis and abundances were $\log_{10}$ transformed prior to calculations. Analysis of Variance (ANOVA) was performed comparing areas by date. After examination for normality, abundance values were $\log_{10}$ transformed prior to testing. Where significant differences ($p<0.05$) were encountered in the ANOVA a Tukey-Kramer Highly Significant Difference (HSD) test was performed on the means.

RESULTS

General Results

A grand total of 37 taxa and 35,818 fishes was collected during 2002 and 2003 (Appendix Table 1). High numbers of species and high total numbers of fish in the catch generally co-occurred in late summer and early fall sampling periods (Figures 3 and 4). Samples were overwhelming dominated by the Atlantic silverside, *Menidia menidia* (35%) and menhaden, *Brevoortia tryannus* (30%) with anchovies (*Anchoa mitchelli* and *A. hepsetus*) contributing another 16% to the total catch (Table 2). Weakfish, *Cynoscion regalis*, bluefish, *Pomatomus saltatrix*, and winter flounder, *Pleuronectes americanus*, constituted 7.9%, 3.9%, and 1.5% of the catch respectively.

Analysis of Variance (ANOVA) detected no significant difference ($p>0.05$) in total numbers of fishes/seine haul among areas but did find differences between sampling dates and among areas within sampling dates (Table 3). Total numbers of fishes collected during September 2002, August 2003, and October 2003 were significantly higher ($p<0.05$) than all other sampling dates (Figure 4). The only significant difference ($p<0.05$) among areas within individual sampling dates was September 2003 when Port Monmouth had more fishes than Keansburg. Union Beach did not differ from the other two areas at this time (Table 3).

Total numbers of silversides were highest in September of 2002, August 2003, and again in October 2003 (Figure 5). Menhaden densities peaked in September 2002 and October and November of 2003. Anchovies were most abundant in June and September of 2003 while weakfish were found in the greatest numbers in August 2003. Bluefish abundances were high in September 2002 and July and October of 2003. Winter flounder densities were greatest between June and August of 2003.

Non-Metric Dimensional Scaling (MDS) followed by Analysis of Similarity (ANOSIM) failed to detect differences in species composition among areas during any given sampling date (Table 4). Typical MDS plots for these comparisons are presented in Figures 6 and 7. A 2-Stage MDS plot of monthly data indicated changes in species composition between September 2002, October 2002, June 2003 and the remaining sampling periods (Figure 9). Comparison of the monthly catches for these time periods indicate that windowpane, American eels, and Atlantic herring were most abundant in the September 2002, October 2002, and June 2003 collections, while menhaden, weakfish, winter flounder, and cunner were most numerous in the remaining sampling periods (Appendix Table 1).

Size Structure

<u>Silversides</u>

An estimated total of 12,553 silversides was collected between September 2002 and November 2003 (Table 2) of which 4,533 were measured. Sufficient numbers of fish were collected in all sampling periods to construct size frequency histograms (Table 5). Silversides from September and October 2002 seine hauls were dominated by the 61 mm-75 mm and 71 mm-95 mm fish respectively (Figure 10). In June 2003 the 91-105 mm size range dominated the catch, but in the following month fish were much smaller and more evenly distributed within a 31-71 mm size range. Beginning in August 2003 silversides exhibited progressive growth each month; in August they were primarily 71-85 mm size range and by November the 96-110 mm size range was dominant.

Silverside population size structure was nearly identical at all three areas with most fish ranging from 71 to 85 mm in total length (Figure 11). However, size varied unpredictably among the beaches between sampling dates (Table 7). Silversides were largest at Port Monmouth in October 2002, and October and November of 2003.

Keansburg had the highest average size during June and August 2003. Union Beach had the largest size fish in September 2002, July 2003, and September 2003.

Menhaden

An estimated total of 10,904 menhaden was collected in 2002 and 2003 (Table 2) of which 1,519 were measured for size frequency analysis (Table 5). Size frequency histograms could be constructed for all sampling periods except June 2003. Menhaden population size structure changed dramatically between sampling periods and among areas. In 2002, fish between 41-50 mm dominated September collections and fish 51 -60 mm made up most of the October seine hauls (Figure 12). In June and July catches most menhaden ranged from 41-55 mm, but by August fish 31-50 mm comprised most of the population. In October 2003 fish sizes were very evenly distributed between 41 mm and 90 mm. During November 2003 there appeared to be two different sized populations present: one ranged from 36-45 mm in length, while the other ranged from 81 mm to 100 mm.

These size differences were also obvious among the three areas. Menhaden collected at Port Monmouth had a size structure similar to that of the November 2003 samples with peaks in abundance at 41-50 mm and 76-90 mm (Figure 13). Keansburg consisted primarily of 41–65 mm, 66–80 mm, and 91-100 mm fish. Union Beach menhaden generally ranged 46-55 mm. There was sufficient variation in size structure among the areas over time to suggest that size comparisons among areas are inadvisable (Table 7). The average size of menhaden was greatest at Port Monmouth in October 2002 and September and November of 2003. Keansburg populations had the largest average size animals in August and October 2003. Menhaden were largest at Union Beach only in September 2002.

Anchovies

Almost 6,000 anchovies were collected between September 2002 and November 2003 (Table 2) of which 1,436 were measured (Table 5). Anchovy populations in September 2002 and October were mostly 41-60 mm. In June 2003 56-79mm fish dominated the population. In July 60-80 mm fish were most common and in August the majority were 71-90 mm long (Figure 14). By September 2003 most fish were 56-80 mm and in October most ranged between 51-75 mm. There appears to have been a second peak in abundance at this time in the 81-90 mm size range. By November 2003 most anchovies were 66-95 mm.

Differences in anchovy size structure were minimal between the three areas (Figure 15). Fish at Port Monmouth and Keansburg were most commonly in the 61-75 mm size range, while at Union Beach most fish were between 56-75 mm. As with the previous species, average fish lengths varied unpredictably among the areas over time (Table 8). Average anchovy length was greatest at Port Monmouth in October 2002 and June 2003, highest at Keansburg in August, September and November 2003, and highest at Union Beach in September 2002, and July 2003.

Weakfish

A total of 2,842 weakfish was collected over the course of the study and 581 were measured (Tables 2 and 5). Sufficient numbers of animals to construct size frequency histograms were collected only in August, September, and October of 2003 (Figure 16). August samples were dominated by weakfish fish 51-65 mm long, September samples by 81-90 mm fish, and October samples by 96-115 mm fish.

Weakfish size varied somewhat among the three areas but these differences appear to be minor (Figure 17). Port Monmouth weakfish were slightly longer those of the other areas, however fish ranging from 51-65 mm dominated all three areas. When fish size is compared among areas over time, Port Monmouth had the largest fish in September 2003, Keansburg the highest average length in August and Union Beach the highest average length in October 2003 (Table 9).

Bluefish

A total of 1,421 bluefish was collected between September 2002 and November 2003 of which 937 were measured (Tables 2 and 5). Sufficient numbers of bluefish were collected to construct size frequency histograms for all sampling periods except June and November 2003. Bluefish collected in September of 2002 were predominately in the 71-80 mm size range, while specimens in the 131-150 mm size range were prevalent in samples from the following month (Figure 18). In 2003, the 101-115 mm size range dominated July collections. The 141-150 mm size range was dominant in August and the 91-100 mm size range in October. September 2003 samples yielded a minimal sample (33 fish) in which the 106-115 mm size range was predominant. There did not appear to be a consistent trend in bluefish sizes over time and most fishes encountered were in the 90-120 mm size range.

Bluefish from Port Monmouth appear to have been slightly larger than those from the other areas with the 91-105 mm fish dominating the population (Figure 19). Sizes of bluefish at both Keansburg and Union Beach were more evenly distributed, ranging from 61-110 mm. There was no pattern to the average bluefish size collected among areas over time (Table 10). In September 2002 the average size of bluefish differed by 4.4 mm among the three areas and was greatest at Union Beach. The following October and again in June 2003 specimens differed by slightly more than 6 mm and were longest at Port Monmouth. In July and August 2003 average size differed by more than 10 mm and was greatest at Keansburg. Bluefish were only encountered at Port Monmouth in the remaining collections.

Winter Flounder

A total of 566 winter flounder was captured and measured over the course of the study (Tables 2). Sufficient numbers of animals to construct size frequency histograms were collected only in the 2003 samples (Table 5). Winter flounder uniformly increased in size between sampling periods beginning with a population dominated by 26-45 mm fish in June and ending with one dominated by 51-75 mm fish in November 2003 (Figure 20). There was no distinct difference in population size structure among the areas (Figure 21) and no pattern to which area had the highest average size over time (Table 11).

Fish Feeding Habits

Silverside Feeding Habits

Approximately 15% of the more than 2,900 silverside stomachs examined were empty. The proportion of empty stomachs varied over time and among areas but seldom-exceeded 20% of all stomachs examined (Figure 22). The highest proportion of empty stomachs (~40%) occurred at Union Beach in August 2003. The second highest (~30%) was at Keansburg in September 2002. The percentage of empty stomachs ranged from 10-15% for individual size ranges with the exception of the 46-50 mm and 76-80 mm size ranges, which approached or exceeded 20% and size ranges at the extremes of the size range (< 40 mm or > 96 mm) that were less than 10% (Figure 23).

Larvae and eggs of the horseshoe crab, *Limulus polyphemus* were the most important food item in the silverside diet in terms of relative abundance, frequency of occurrence and contribution to biomass (Table 13; Figures 24-26). They were the single largest component of prey biomass during all sample periods except October 2003, when presumably their availability had declined. Small fish (probably anchovies), amphipods, and crangonid and palaemonitid shrimp dominated the October 2002 samples, however this was attributable entirely to samples from Keansburg. Other important prey items encountered over the period of the study included the mysid *Neomysis americana*, insects (primarily flying ants), and amphipods (primarily *Corophium* sp. and *Ampelisca abdita*). Mysids and amphipods were especially abundant in stomach contents from June to August 2003. Food items of lesser importance included the gem clam, *Gemma* gemma, the polychaete *Sabellaria vulgaris*, and isopods. Food items occurring frequently, but making up relatively little of the total prey volume included copepods, the alga *Ulva* spp., and fish scales.

A similar dominance pattern is apparent in the comparisons of food habits samples among areas (Figures 27-29). Silversides at Port Monmouth and Union Beach fed primarily upon *Limulus*, *Neomysis*, and shrimp while at Keansburg fish biomass dominated the diet. Fish were an infrequent prey item (Figure 28), but when present tended to dominate prey volume. When Keansburg prey biomass was examined without the fish component *Neomysis* became the most important prey item (Figure 30).

The relative importance of different prey items changed with increasing silverside size. Small fish (< 60 mm) fed mostly on mysids, amphipods, insects, and *Limulus* larvae and eggs (Figures 31-32). Although they made relatively little contribution to relative abundance (Figure 33), horseshoe crab larvae and eggs constituted almost 50% of the prey biomass in small silversides (Figure 34). The same is true for the larger fish with the exception that the horseshoe crabs comprise a greater proportion of relative abundance and occur more frequently. Larger fish also fed on decapods (mostly shrimp), mysids, amphipods, and polychaetes (Figures 31-32).

Bluefish Feeding Habits

A total of 997 bluefish was dissected and their stomach contents examined (Table 5). Approximately 15% of all the stomachs examined were empty with the highest proportion of empty stomachs occurring at Union Beach (>40%) in July 2003 (Figure 35). There was a higher proportion of empty stomachs in small bluefish (<70 mm) than larger fish (Figure 36).

The prey of bluefish tended to be fishes, shrimp (*Crangon septemspinosa* and *Palaemonetes* sp.) and the mysid shrimp *Neomysis americana* (Table 13; Figures 37-39). Mysid shrimp were particularly important in June and July of 2003, while crangonid and palaemonitid shrimp were important primarily in August and September 2003. There were no clear distinctions in bluefish diets between areas (Figures 40-43), but there were differences among fishes of different sizes (Figures 44-45). Bluefish less than 120 mm fed heavily on mysids as well as fish and shrimp. Those greater than 120 mm relied primarily upon fish and *Crangon*. From this data, it would appear that small bluefish entering the project area in late spring and summer concentrate on smaller prey such as mysids, then shift to larger prey as they increase in size.

Weakfish Feeding Habits

Five hundred eighty one weakfish were measured and dissected for stomach content examinations (Table 5). Sufficient specimens were present to describe feeding habits for Port Monmouth and Union Beach (Figures 46-48) and eight 5-mm size classes (Figures 49-51). Insufficient specimens were collected to examine variation among collection dates.

Crangon was the dominant prey comprising more than 50% of all items encountered (Table 13). Fishes were the second most abundant food item, followed in importance by grass shrimp (*P. pugio*), the amphipod *Ampelisca abdita,* and *Limulus* larvae. Shrimp (*Crangon* and *Palaemonetes* combined) made up a greater proportion of the food items by relative abundance and biomass and occurred more frequently in stomachs from Union Beach than Port Monmouth (Figures 46-48 and 52). Fishes (including fish scales) followed the same pattern of abundance and occurrence.

Shrimp and fish dominated relative abundance, occurrence, and biomass of all weakfish size classes. Amphipods, primarily *A. abdita,* were also frequently found in all size classes (Figure 50), but they were most important in the 66-70 mm size class and to a lesser extent the 71-75 mm size class (Figures 49 and 51).

Winter Flounder Feeding Habits

Five hundred fifty winter flounder were collected, measured, dissected, and their feeding habits examined (Table 5). Insufficient specimens were collected to examine differences among collection dates, however all areas and 12 5-mm size classes ranging from 31 to 75 mm could be compared.

Polychaetes and amphipods (and other crustaceans) were the dominant prey items at all three areas for all size classes (Figures 53-58). Polychaetes contributed 50% or more to relative abundance at Port Monmouth and Union Beach (Figure 53) and roughly 30% at Keansburg (Figure 55). The polychaete component was dominated by the spionids *Streblospio benedicti* and *Polydora* sp. and by unidentifiable spionid remains (Table 13; Figure 59). *Phylloduce* sp. and *Sabellaria vulgaris* also contributed to overall polychaete abundance. *Phylloduce* sp. was most abundant in fishes collected from Port Monmouth and Union Beach, while *S. vulgaris* was found principally in specimens from Port Monmouth. Amphipods, another important food item, were dominated by *A. abdita* and *Corophium insidiosum* (Table 13; Figure 60). *Ampelisca* was most abundant in fishes collected at Keansburg and Union Beach, while *Corophium* was most abundant in fishes from Port Monmouth. Molluscs, dominated by bivalve siphons (most likely juvenile *Mya arenaria* siphons) and the gem clam *Gemma gemma* became increasingly abundant in the larger sized juvenile winter flounder (51-75 mm) and were particularly important (>25%) in the 71-75 mm size class (Figure 58).

Northern Kingfish Feeding Habits

A total of 274 northern kingfish was collected, measured and dissected for food habits examinations. Sufficient numbers of specimens were collected to distinguish among areas and four 5-mm size classes, but not among dates. The diet was dominated by shrimp (*C. septemspinosa* and *P. pugio*) and crabs (a mixture of pagurids, xanthids and portunids) (Table 13). The relative abundance of these food items varied among areas. Port Monmouth had the highest proportion of shrimp (~66%), while they made up only less than 35% at the remaining areas (Figure 61). Crabs constituted 41-51% of relative abundance at Keansburg and Union Beach, but only 7% at Port Monmouth. Values for frequency of occurrence followed similar patterns (Figure 62). Biomass distribution differed from these patterns primarily in the increased importance of shrimp (~56%) at Union Beach (Figure 63).

Feeding habits differed among size classes principally in the increasing importance of crabs and decreasing importance of shrimp in the diet with increased fish size (Figures 64-66). Shrimp comprised more than 50% of relative abundance and 85% of total biomass in fish ranging 101-120 mm in length. Shrimp made up only 25% or less of relative abundance and biomass in fish 161-180 mm in length, while crabs constituted more than 75% of relative abundance and biomass in these fishes.

Windowpane Feeding Habits

A total of 252 windowpane was collected. All specimens were measured, and food habits examined. Sufficient specimens were collected to compare diets among areas (Figures 67-69). There were also adequate numbers of specimens to describe food habits for five 5-mm size classes. These distributions are described rather than illustrated because of the uniformity of the results.

The mysid shrimp *Neomysis americana* was the predominant food item in windowpane from all three areas. It dominated relative abundance by at least 75% in all areas, frequency of occurrence by 65% or more, and biomass by 50% or more (Figures 67 and 69). Shrimp (*C. septemspinosa* and *P. pugio* in nearly equal proportions, Table 13) were important especially in biomass distributions at Union Beach (>50%) and to a lesser extent at Keansburg (Figure 69). Amphipods, dominated by *A. abdita*, were also an important component of relative abundance, occurrence, and biomass at Keansburg.

DISCUSSION

General results

Previous studies of Raritan Bay, Sandy Hook Bay, and Lower New York Harbor have characterized the abundance and seasonal occurrence of fishes of open-bay waters (e.g., Berg and Levinton 1985, Wilk *et al*. 1977,Wilk *et al*. 1996), but not those of shallow intertidal areas. Comparison of open-bay fish collections to those of the present work suggests the presence of two assemblages (Table 12). The first assemblage consists of those species characteristic of the deeper open-bay waters such as butterfish, *Peprilus triacanthus* and skates (Rajidae). The second assemblage could be described as bay-wide dominants, which differ between depths principally in their relative abundance. For instance, silversides were seldom collected in the open-bay, but were the most abundant species in the intertidal samples. Menhaden, weakfish, bluefish, and northern pipefish were also far more abundant in beach collections than the open-bay. Alewives (*Alosa pseudoharengus*), blueback herring (*A. aestivalis*), scup (*Stenotomus chrysops*), striped and northern sea robins (*Prionotus evolans* and *P. carolinus* respectively) southern flounder (*Paralichthys dentatus*), winter flounder and windowpane (*Scophthalmus aquosus*) were more abundant in the open-bay than along the shore.

Anchovies were equally abundant in both habitats. Fishes occurring in low abundance, but only in the shallows included killifish (*Fundulus heteroclitus* and *F. majalis*), Atlantic needlefish (*Strongylura marina*), permit (*Trachinotus falcatus*), and striped bass (*Morone saxatilis*). Fishes present in abundances too low to determine if their distributions differed between depths included northern kingfish (*Menticirrhus saxatilis*), cunner (*Tautogolabrus adspersus*), tautog (*Tautoga onitis*), and lookdown (*Selene vomer*).

Seasonal abundances of fishes were very similar between open-bay and shallow-water studies. Wilk *et al*. (1996) collected the greatest numbers of fish in open-bay waters during mid-summer (July and August of 1992 and June and July of 1993). The 1992 results reflected a peak in abundance of scup in July and butterfish in August. The 1993 results corresponded to high abundances of scup, hakes, and winter flounder. Anchovies were most abundant in June and October of 1992 and again in October 1993. In the present study abundances were highest in September 2002 and August and September of 2003 (Figure 4). Silversides dominated abundance during the first date, silversides and weakfish dominated the second, and anchovies were the most abundant taxa during the last (Figure 5). A final peak of abundance in November 2003 reflected high numbers of both silversides and menhaden.

Food Habit Studies

<u>Silversides</u>

Aspects of silverside diet have been described by a number of different authors including Gilmurray and Dabor (1981), Cadigan and Fell (1985), Warkentine and Rachlin (1989), and Wilber *et al*. (2003). Gilmurray and Dabor (1981) reported that small silversides (<100 mm) from the Bay of Fundy fed mostly on copepods. The diet of larger fish was composed mostly of the amphipod *Corophium volutator*, cumaceans, and the sand shrimp *Crangon septemspinosa*. Although insects were not a major part of the diet in Gilmurray and Daborn's study, the authors refer to Imre and Daborn (1981), a previous work by where nearly 40% of the diet was composed of non-aquatic insects. The authors reported that most feeding occurred on ebb tides and hypothesized that availability of benthic prey is increased when sediments and associated organisms are resuspended by flood tide-induced turbulence.

The three most common prey items of silversides from a salt marsh-dominated Connecticut estuary were copepods, crangonid and palaemonitid shrimp, and plant material (Cadigan and Fell 1985). Other common prey items included young fish (including *Fundulus* and *Menidia*), polychaetes, and horseshoe crab larvae. There was evidence to suggest that diet varied between different sites within the estuary. Fish from the upper estuary fed primarily upon shrimp, copepods, and unidentified eggs (in order of abundance), while those from the lower estuary fed mostly on plant material, fish and copepods. The winter diet of silversides that migrate offshore into the New York Bight was dominated by the mysid *Mysidopsis bigelowi* and to a lesser extent by copepods (Warkentine and Rachlin, 1989). At the same time, the diet of inshore populations was composed primarily of copepods and the mysid *Neomysis americana*.

Amphipods, copepods and annelids comprised the majority of silverside diets at oceanic beaches along the Atlantic coast of New Jersey (Wilber *et al*. 2003). The amphipods most commonly encountered were *Jassa falcata* and *Hylae plumulosa*. The polychaete fraction of the diet was dominated by *Scolelepis squamata*. Juvenile mole crabs (*Emerita talpoida*), insects, isopods, and shrimp were also common dietary items. Comparison of the prey suggested that silversides were feeding primarily on materials suspended in the water column by wave action. For instance, the amphipod *J. falcata* is inherently benthic in origin, while *H. plumulosus* is typically associated with rocky intertidal habitats. The presence and importance of both in the diet can only be reconciled by resuspension due to wave action since the silversides' strongly hypergnathous (upward orientated) mouth precludes direct feeding in either sandy bottom or rocky intertidal habitats.

Results of silverside food habits examinations from the present study differ from those of previous works only in the importance of horseshoe crab larvae and eggs in the diet. This is not surprising since silversides are opportunistic feeders and horseshoe crab larvae often remain concentrated along the same sandy estuarine beaches where the adults lays their eggs (Botton and Loveland 2003, Botton *et al*. 2003).

<u>Bluefish</u>

Bluefish diets have been described by a large number of authors but most recently by Able *et al*. (2002) for populations along the Atlantic coast of New Jersey. Anchovies and silversides overwhelmingly dominated the diet of oceanic beach bluefish, while silversides and killifish comprised the bulk of the diet for estuarine bluefish. Palaemonitid shrimp and mole crabs were also important prey items in the diet of oceanic beach silversides. Previously, Friedland *et al*. (1988) reported that invertebrates such as *C. septemspinosa, P. vulgaris, and N. americana* were major prey items of young bluefish captured in Sandy Hook Bay. Species dominating the diet varied over time. *Palaemonetes vulgaris* and *C. septemspinosa* provided most of the diet by weight in the first year of the study, *N. americana* dominated the second year and *C. septemspinosa* and *N. americana* were nearly equally important in the third year. Fishes, including silversides, anchovies, and killifish, made up less than 36% of the diet. Steimle *et al*. (2000), also working in Raritan Bay, reported that young bluefish diets were composed mostly of fish, *C. septemspinosa*, and *N. americana*. The majority of fish in the diet were butterfish, silversides, and anchovies. Hartman and Brandt (1995) found that bluefish in Chesapeake Bay fed heavily on anchovies in their first year and primarily on menhaden thereafter. Results from the present study closely resemble those of the previous reports both in the composition of the diet and the observed shifts in prey preference with increasing predator size.

<u>Weakfish</u>

Information on weakfish diet has previously been summarized by Mercer (1989) who indicated that juveniles feed predominately on mysids and anchovies, while mature fish feed principally on whatever clupeid fish species is most abundant within an area. Greacy and Targett (1996) have shown that in Delaware Bay juvenile weakfish feed especially heavily upon the mysid *N. americana* and that the relative dominance of this prey item in the diet varies spatially. Mysids comprised a greater proportion of the diet in mid-bay reaches as compared to lower or upper bay areas. Steimle *et al.* (2000) reported that in Raritan Bay weakfish diets were dominated by *Neomysis*, *Crangon*, *Gammarus*, and fish (predominantly bay anchovy). Results from the present work generally correspond to the results of the previous studies. Weakfish collected in the intertidal seines fed overwhelmingly on crangonid shrimp and fish. Likewise, smaller fishes (<76 mm) had greater proportions of small prey such as amphipods and horseshoe crab larvae than larger fishes.

Winter Flounder

The ecology and diet of winter flounder have recently been summarized by Pereira *et al*. (1999) and Steimle *et al.* (2000). Newly settled juvenile winter flounder feed on primarily on copepods, shifting to amphipods and polychaetes as they increase in size (Frame 1974, Hacunda 1981, Stehlik and Meise 2000, Steimle *et al*. 2001). Ampeliscid amphipods and spionid polychaetes have been reported to be of particular importance to their diet in the New York-New Jersey region (Franz and Tancredi, 1992, Stoner *et al*. 2001, Manderson *et al* 2002). As the fish continue to grow they eventually focus on larger prey items such as hard clam (*Mercenaria mercenaria*) and surf clam (*Spisula solidissima*) siphons and cerianthid anemones (Steimle *et al.* 2000, Burlas, Ray, and Clarke 2001).

Northern Kingfish

Northern kingfish inhabit a wide variety of shallow sandy habitats ranging from estuaries to the surf zone of oceanic beaches (Able and Fahay, 1998). Wilber *et al*. (2003) reported that kingfish from New Jersey oceanic surf zones fed chiefly on polychaetes (especially *Scolelepis squamata*), but also on amphipods, shrimp, mysids, and juvenile mole crab (*Emerita talpoida*). The diets of southern kingfish (*M. littoralis*) collected in South Carolina surf zones were characterized by mole crabs, haustorid amphipods, and polychaetes (DeLancey 1989). Chao and Musick (1977) have reported that stomach contents of northern kingfish from the York River, Virginia were dominated by polychaetes, mysids, and shrimp (both *Crangon* and *Palaemonetes*). Offshore populations appear to feed primarily on decapod crustaceans including *Callianassa, Crangon,* and the lady crab *Ovalipes ocellatus* (Bowman *et al*., 2000 as references in Collette and MacPhee, 2002). The general dominance of crabs and shrimp in Northern kingfish diets from the Raritan Bay- Sandy Hook Bay study area are clearly consistent with these reports.

Windowpane

Previous reports of windowpane diet and a recent review of windowpane ecology by Chang *et al*. (1999) indicate that mysids are the predominant prey of this species. Hacunda (1981) has reported that New England populations fed mostly on *Mysis mixta,* Mid-Atlantic populations feed primarily on *N. americana* (Langton and Bowman 1981, Bowman et al. 2000, Steimle *et al.* 2000, and Ray 2003). Other important prey items include *Crangon*, gammarid amphipods, and fish. Steimle *et al.* 2000 also indicated an increase in the relative importance of larger prey such as *Crangon* in larger fish, although mysids continued to be the most abundant food item. Food habit results from the present study are similar to these reports. Mysids were the dominant prey item and larger prey items such as *Crangon* increased in importance at Union Beach, where a disproportionately high number of large fish were present (Appendix Figure 1).

Other Species

Insufficient numbers of animals were available to analyze diets of several other bottom-feeding species including summer flounder (*Paralicthys dentatus*, n=19), permit (*Trachinotus falcatus*, n=166), and scup (*Stenotomus chrysops*, n=34). These analyses will be performed if future collections supply adequate numbers of specimens.

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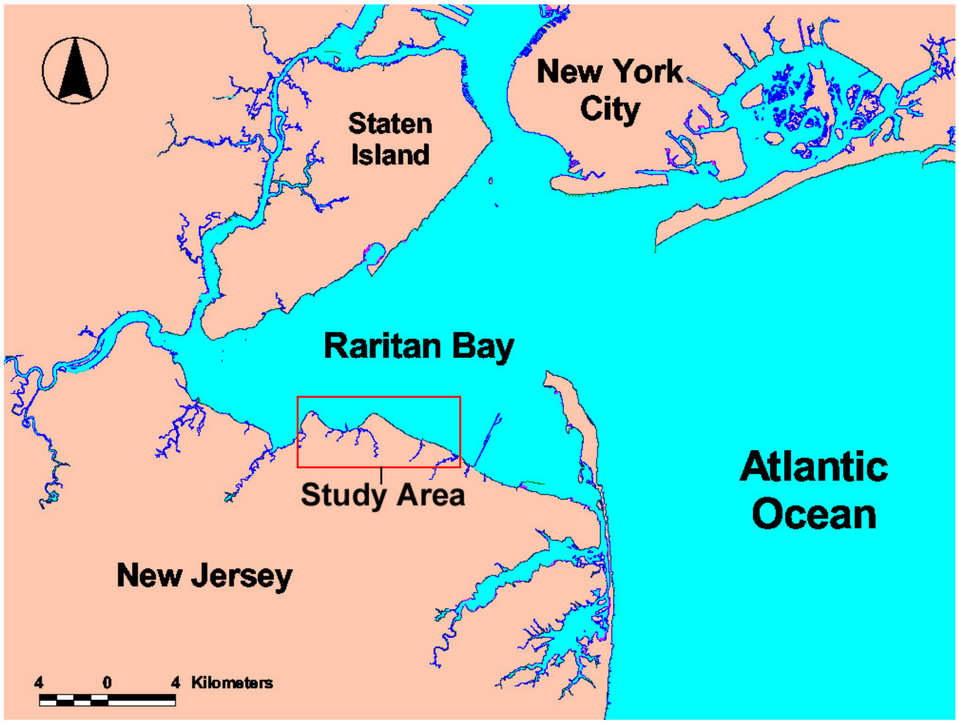


Figure 1. Study Area and Surrounding Waters. Study site indicated by red box.

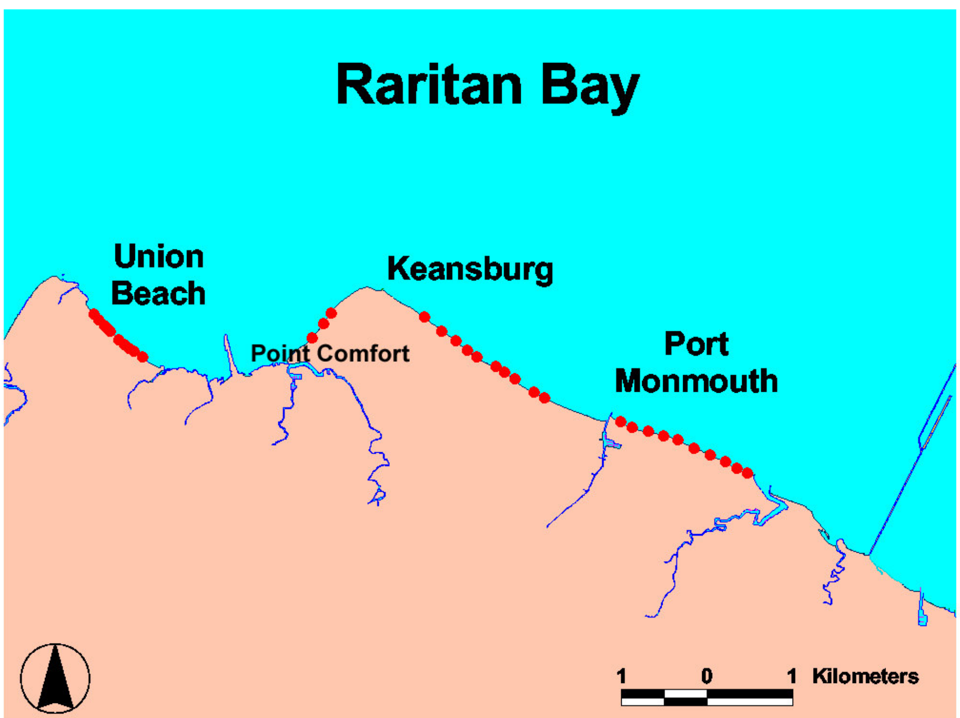


Figure 2. Study Area and Sampling Sites. Individual sampling sites (stations) indicated as red dots.

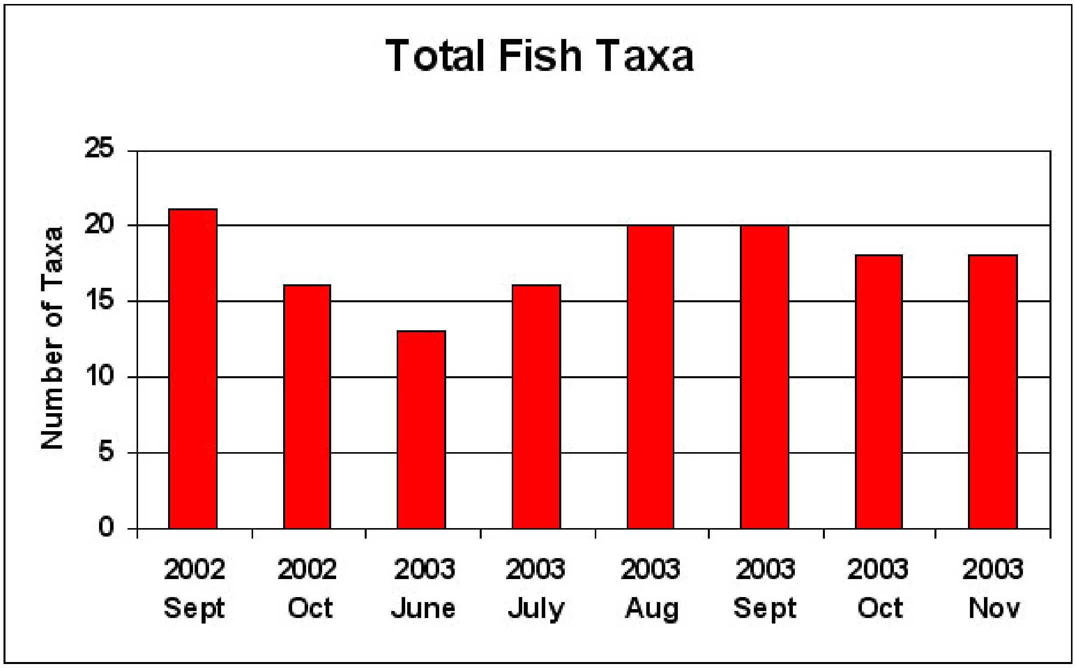


Figure 3. Total numbers of fish taxa collected by date.

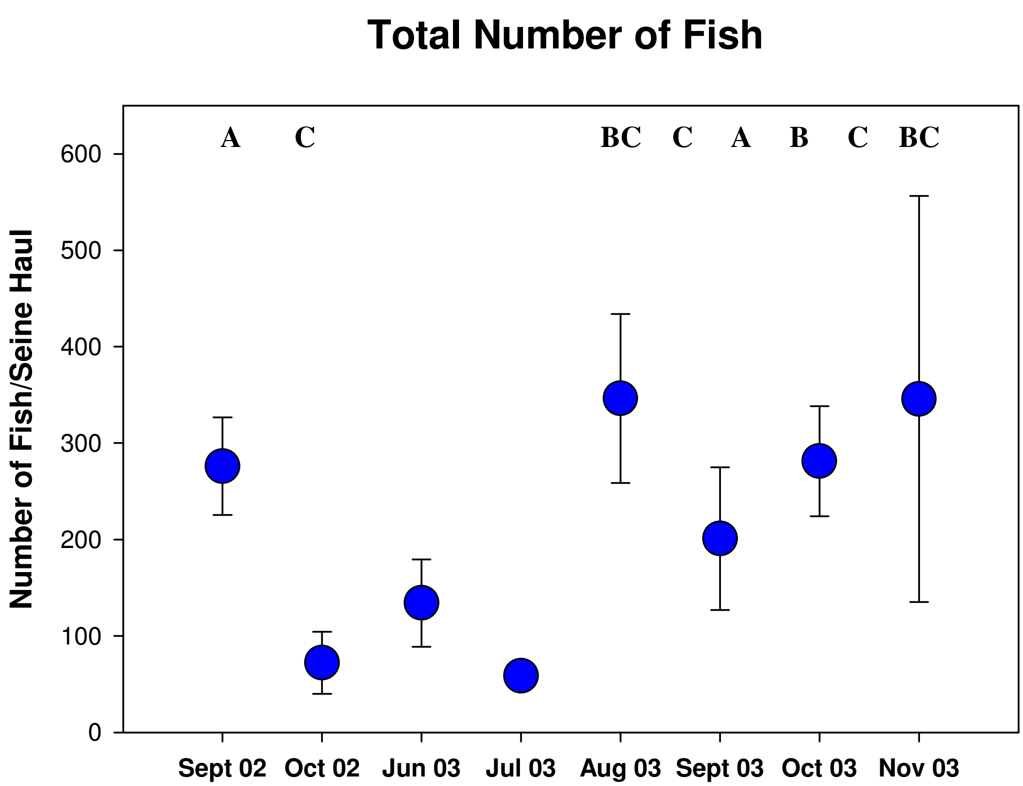


Figure 4. Total numbers of fish collected by date. Means (± SE) with same letter are not significantly different ($p>0.05$) based on Tukey HSD test.

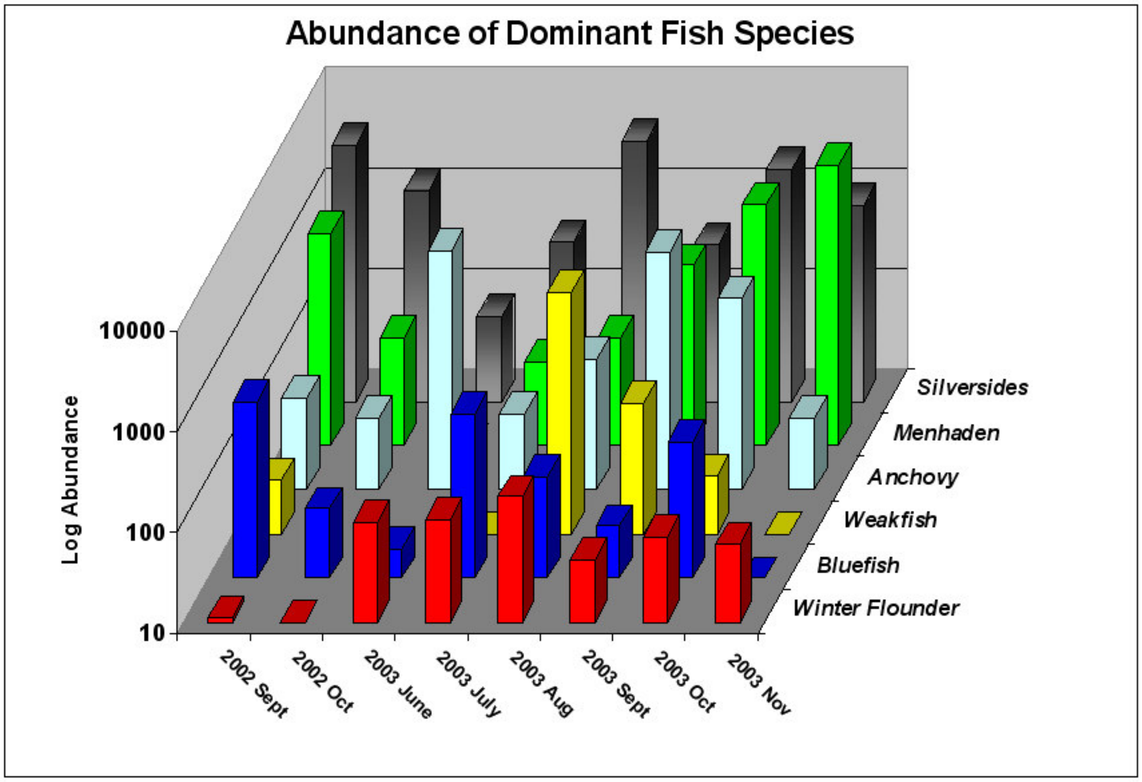


Figure 5. Abundance of dominant fish species.

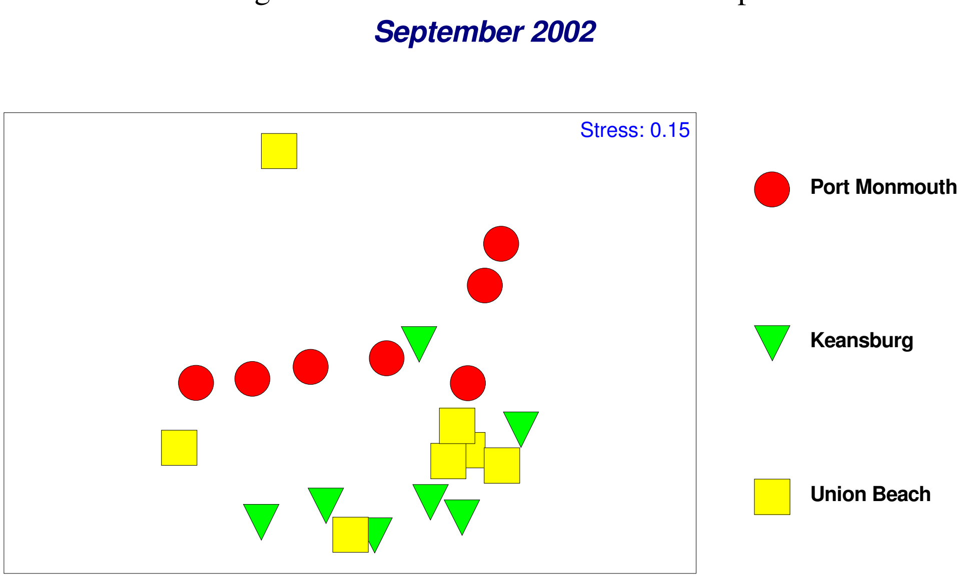


Figure 6. MDS results for September 2002 seine hauls.

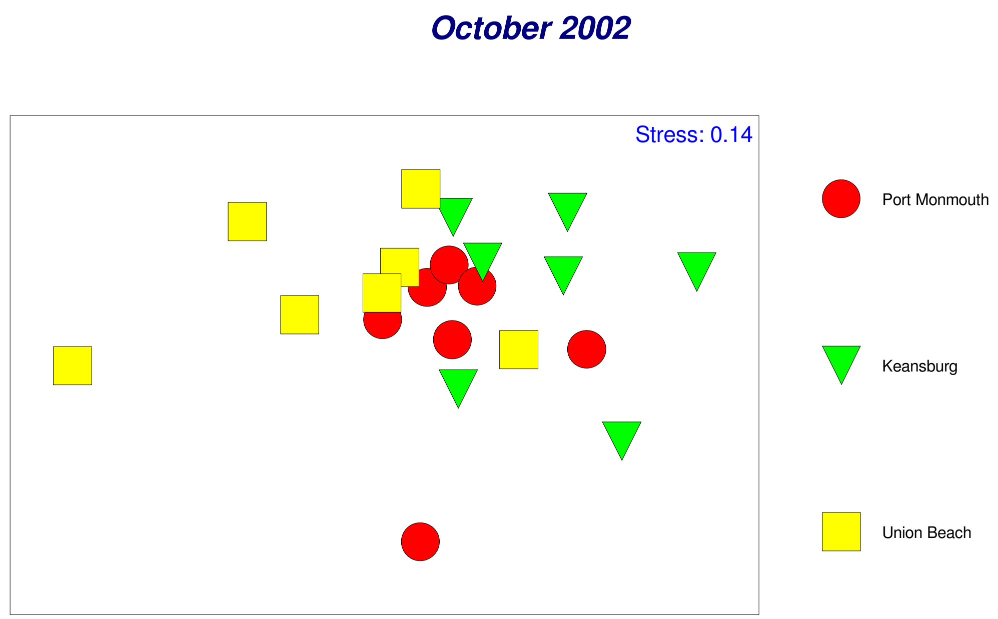


Figure 7. MDS results for October 2002 seine hauls.

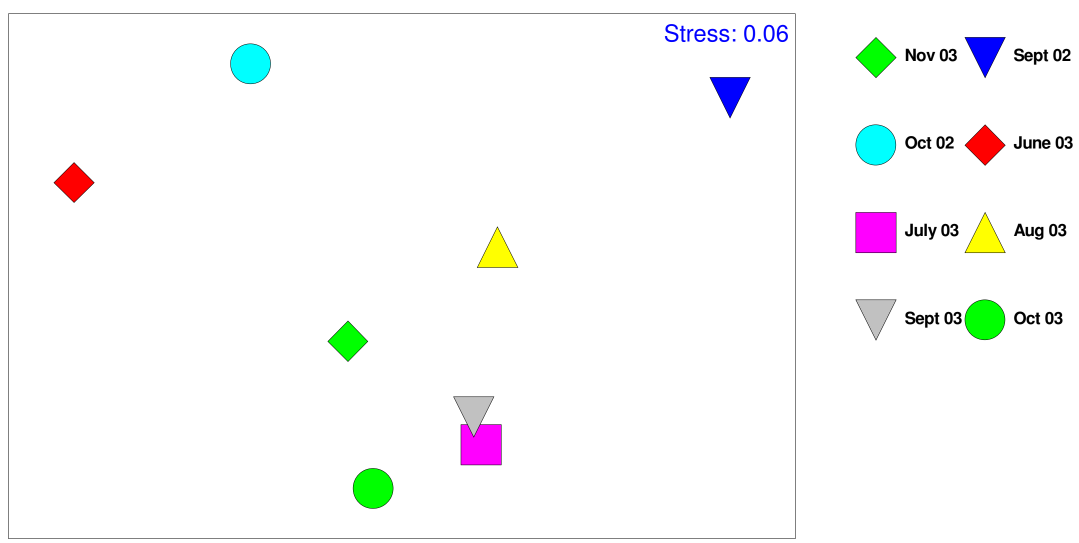


Figure 9. MDS results comparing sample dates.

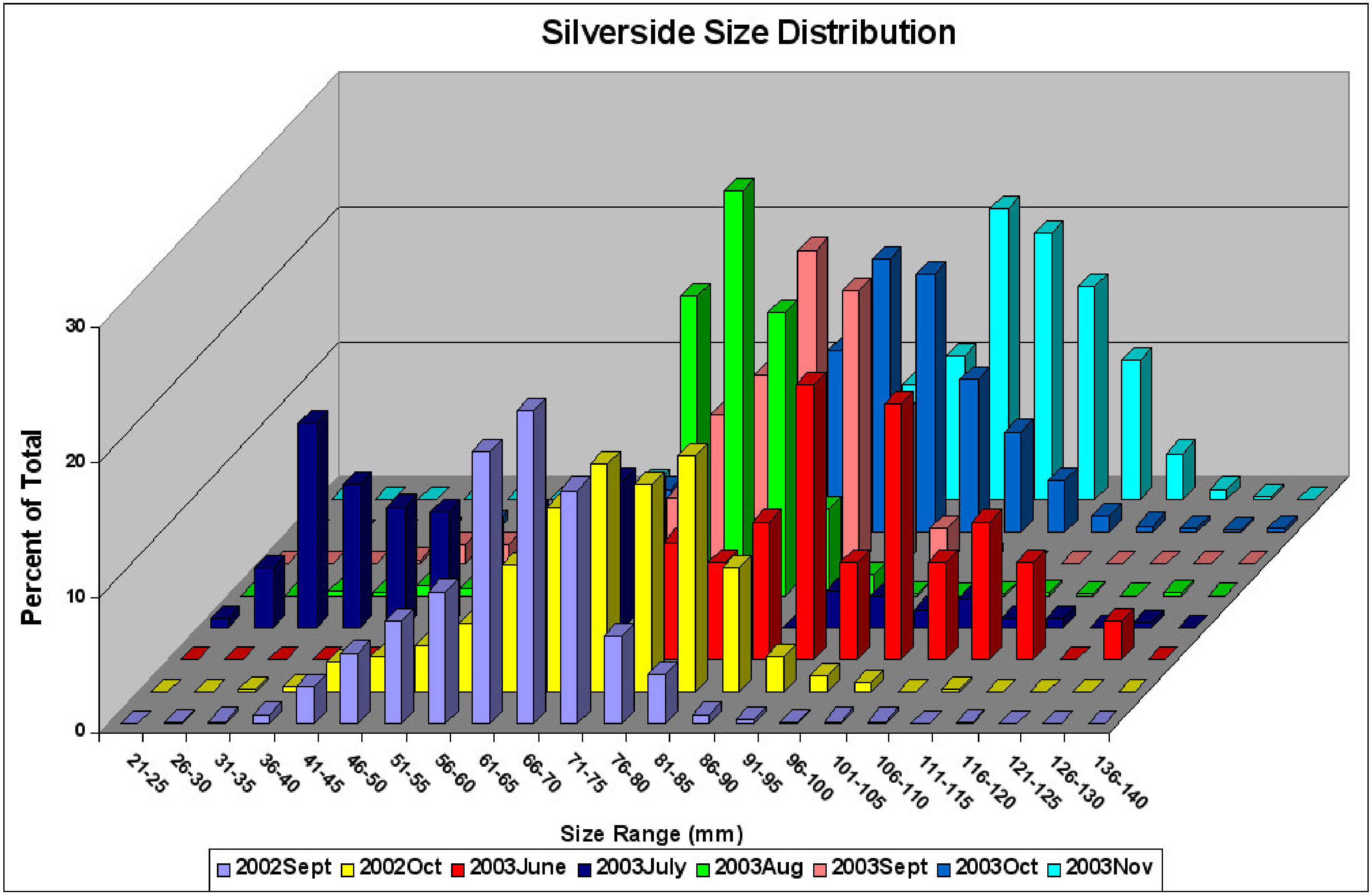


Figure 10. Size distribution of silversides by date

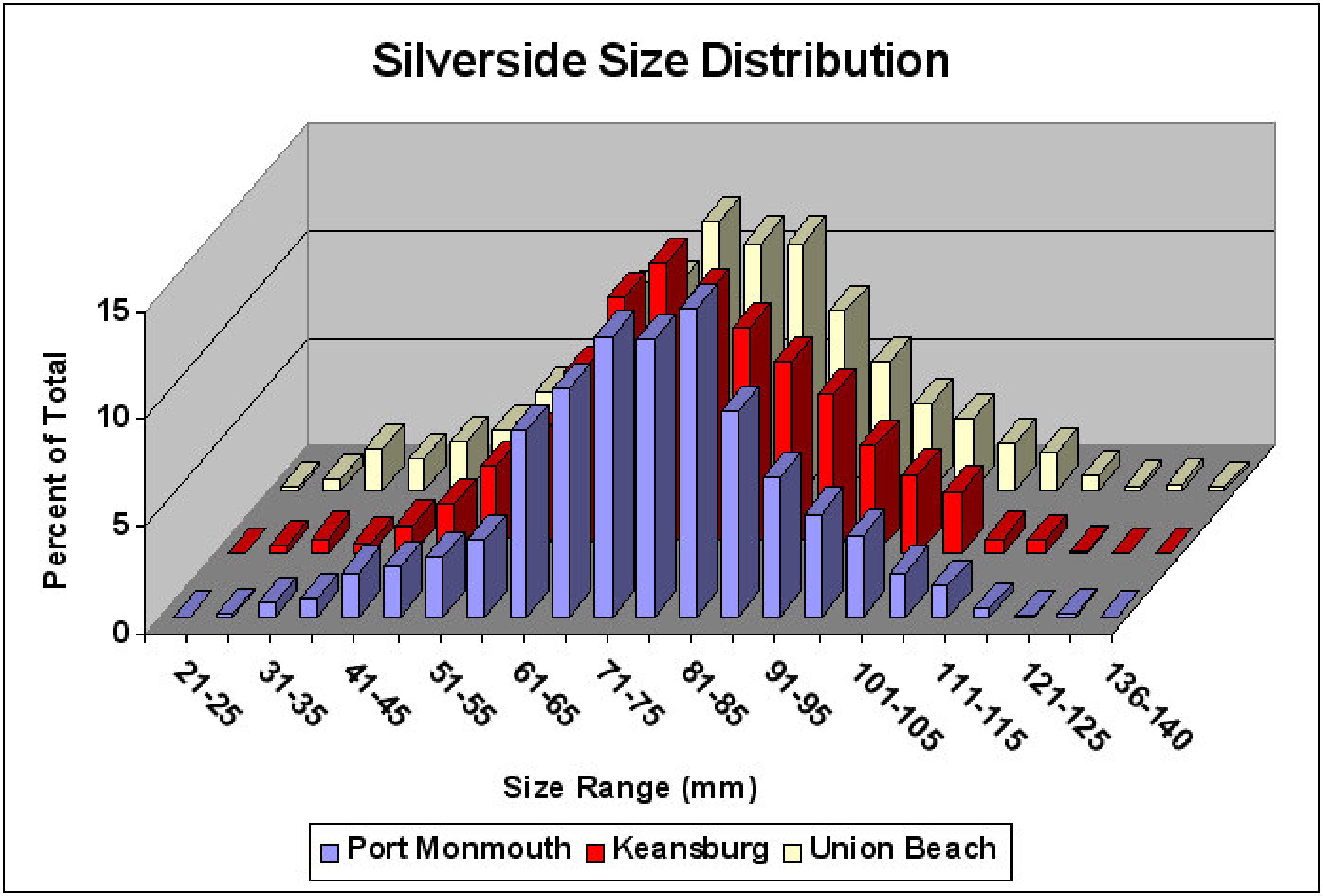


Figure 11. Size distribution of silversides by area

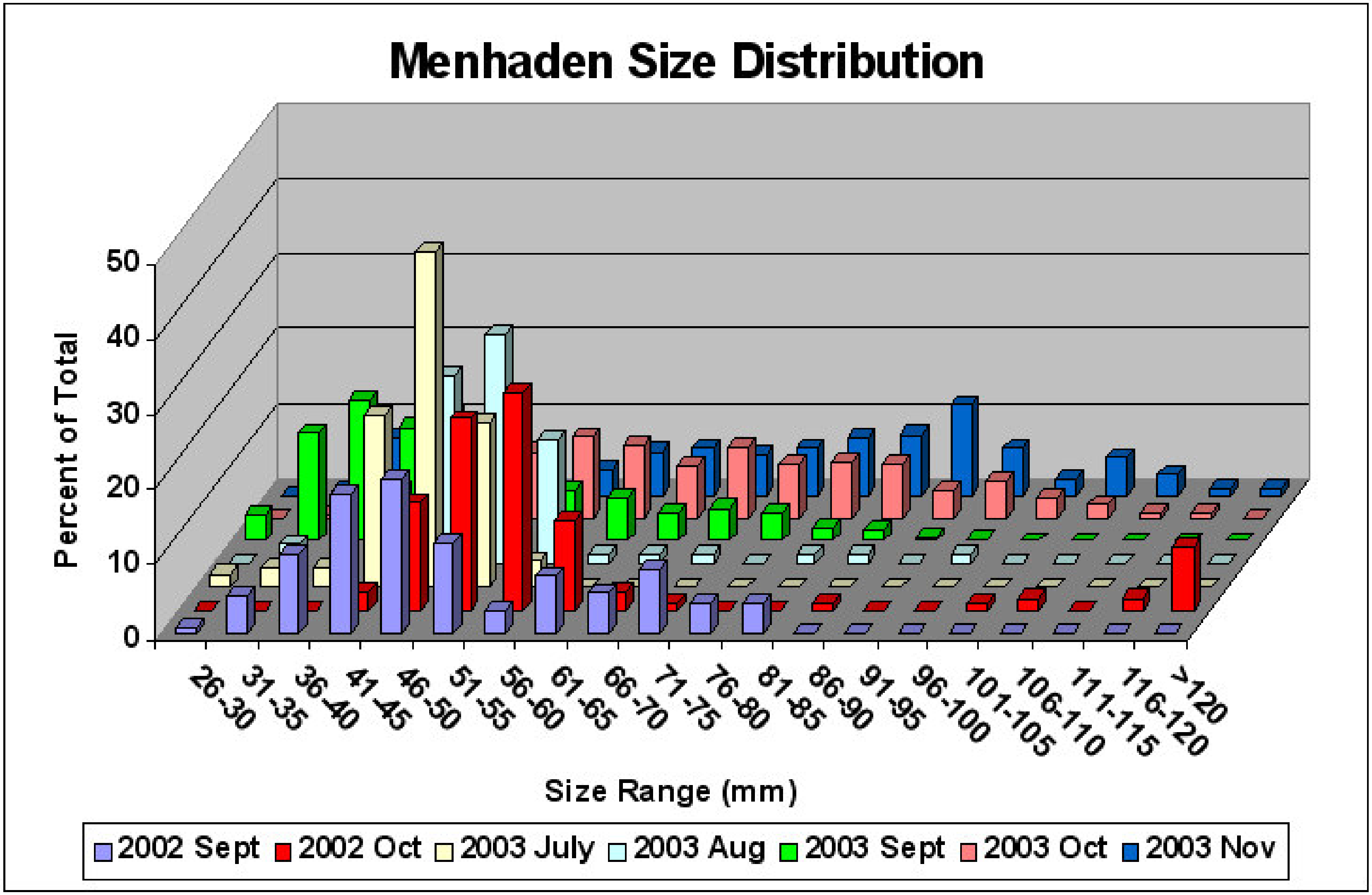


Figure 12. Size distribution of menhaden by date

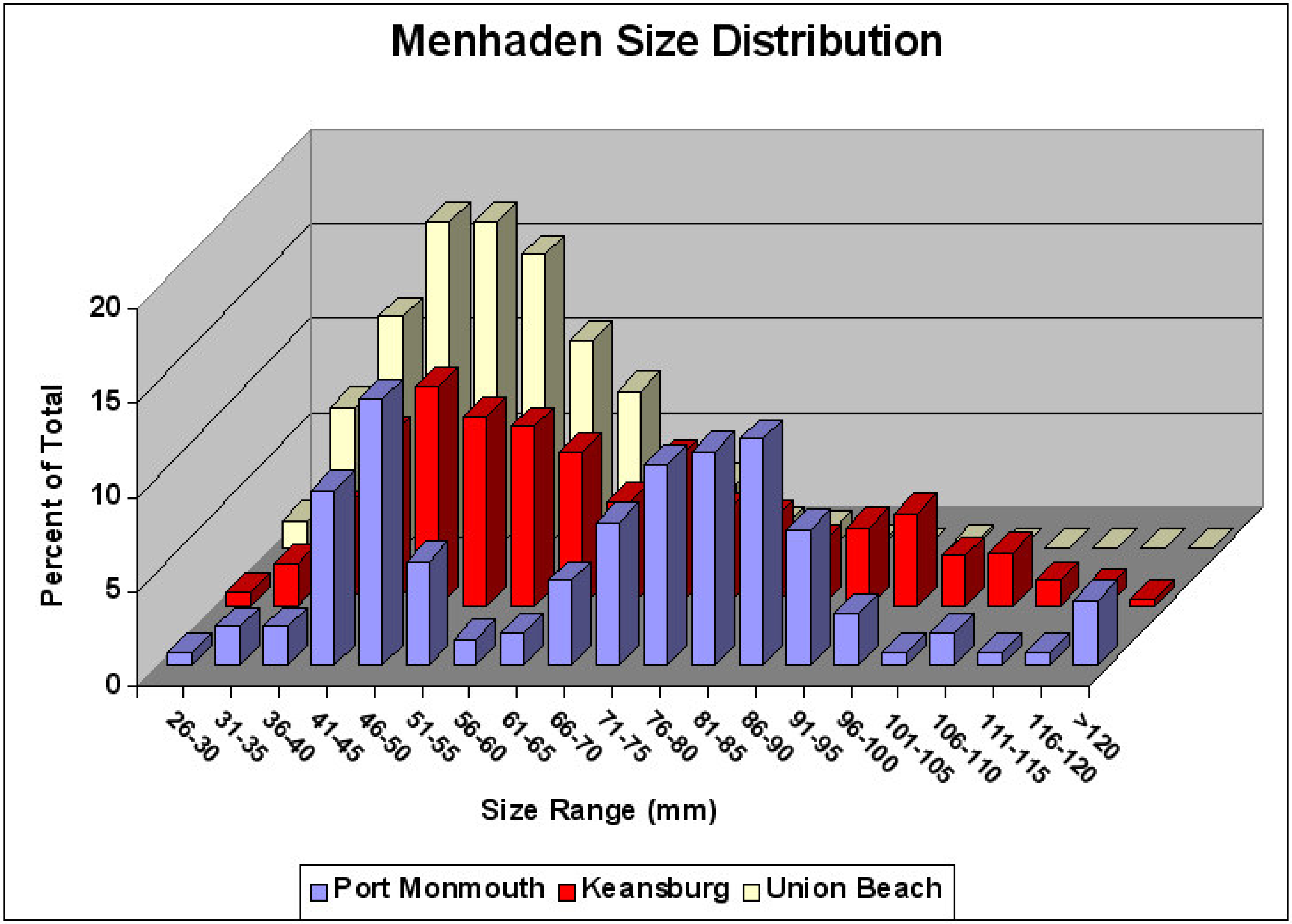


Figure 13. Size distribution of menhaden by area

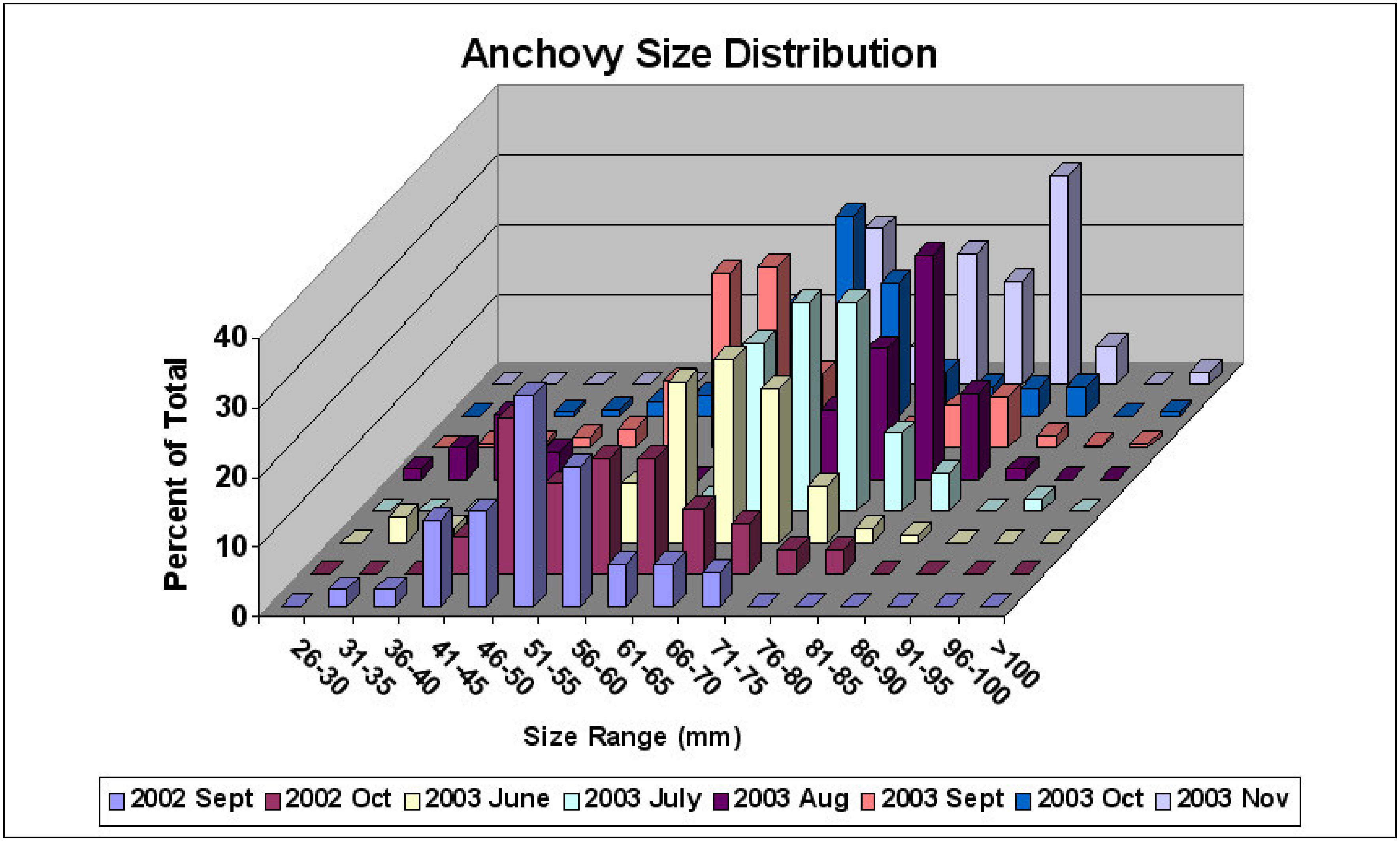


Figure 14. Size distribution of anchovies by date

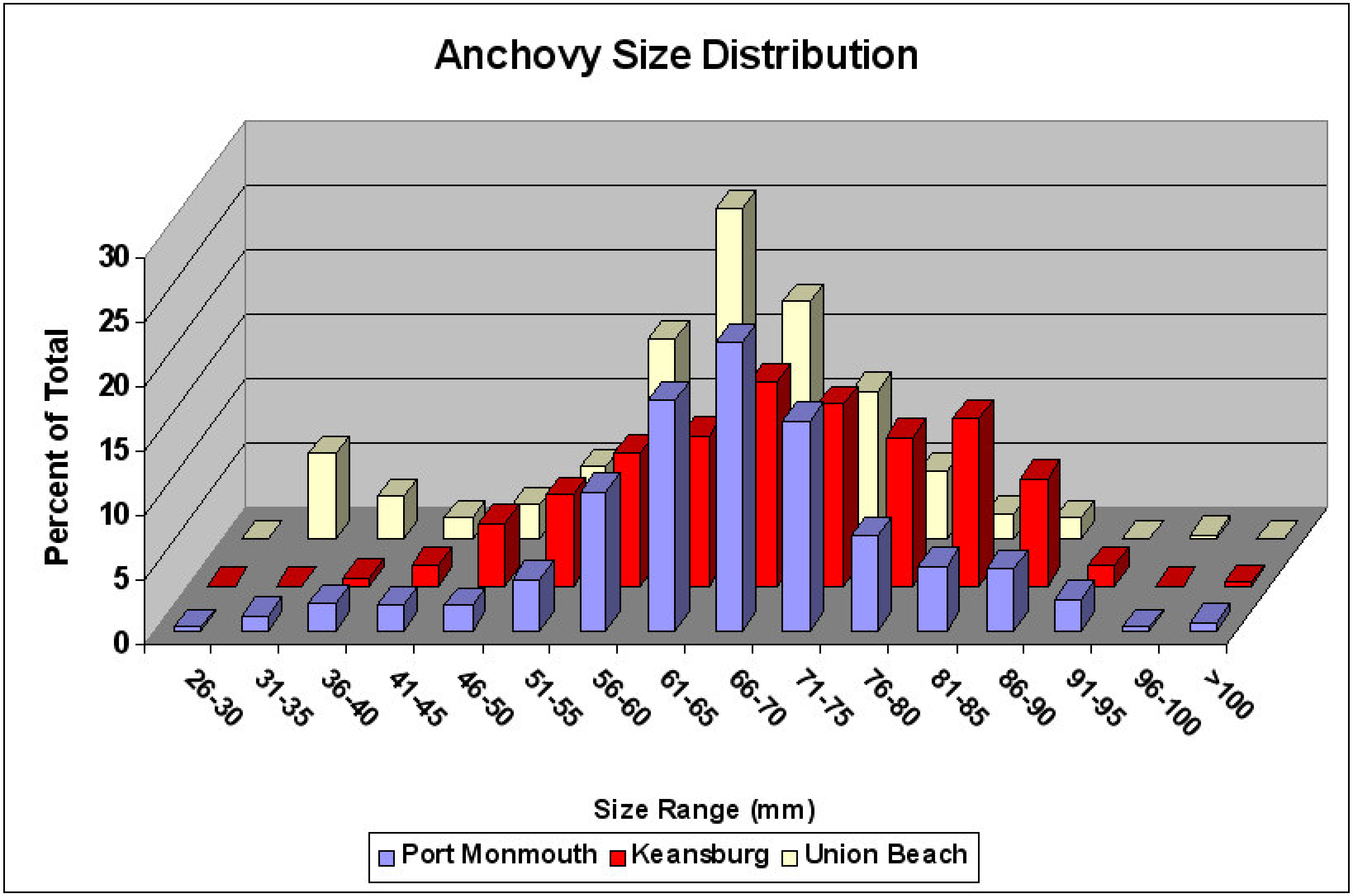


Figure 15. Size distribution of anchovies by area

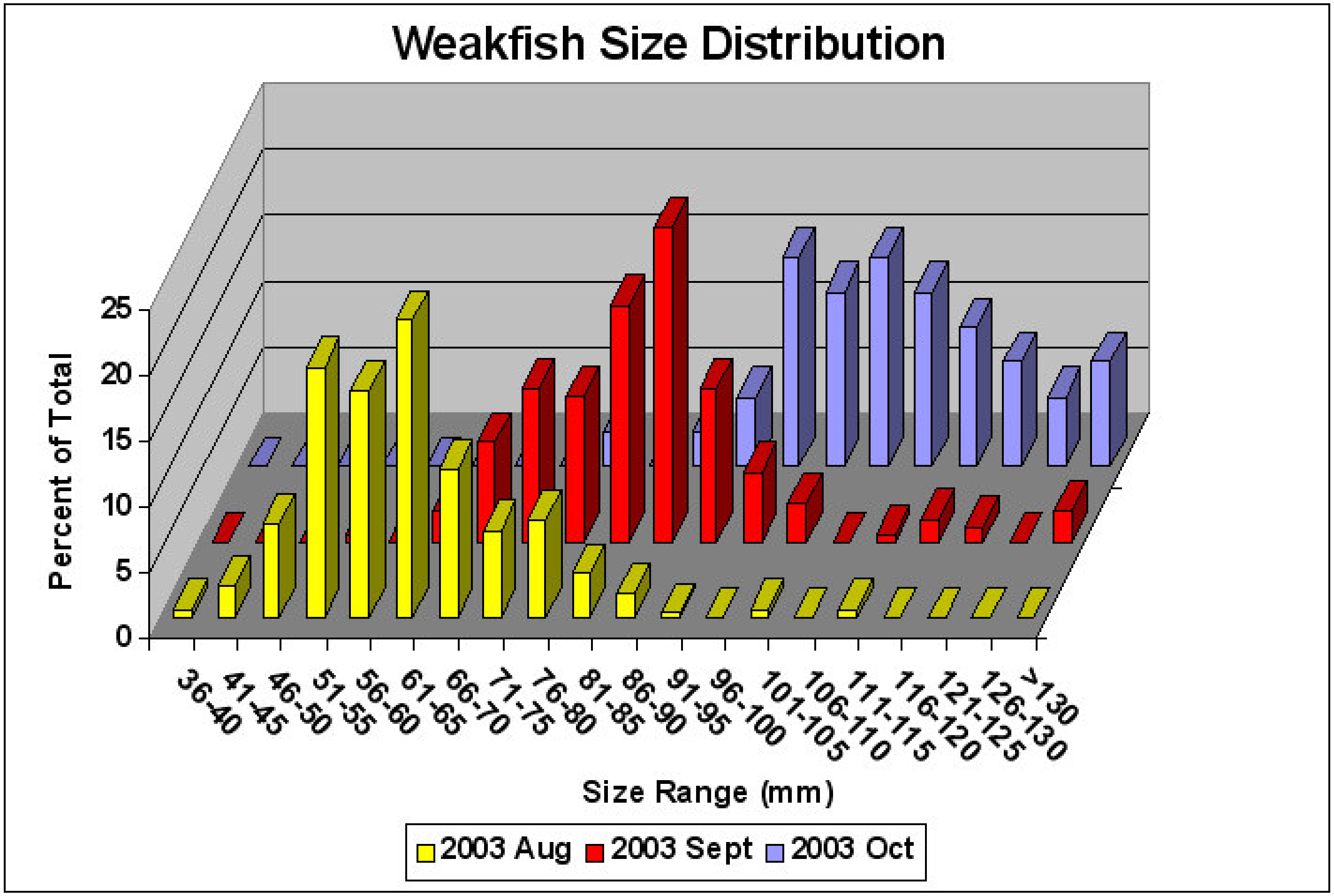


Figure 16. Size distribution of weakfish by date

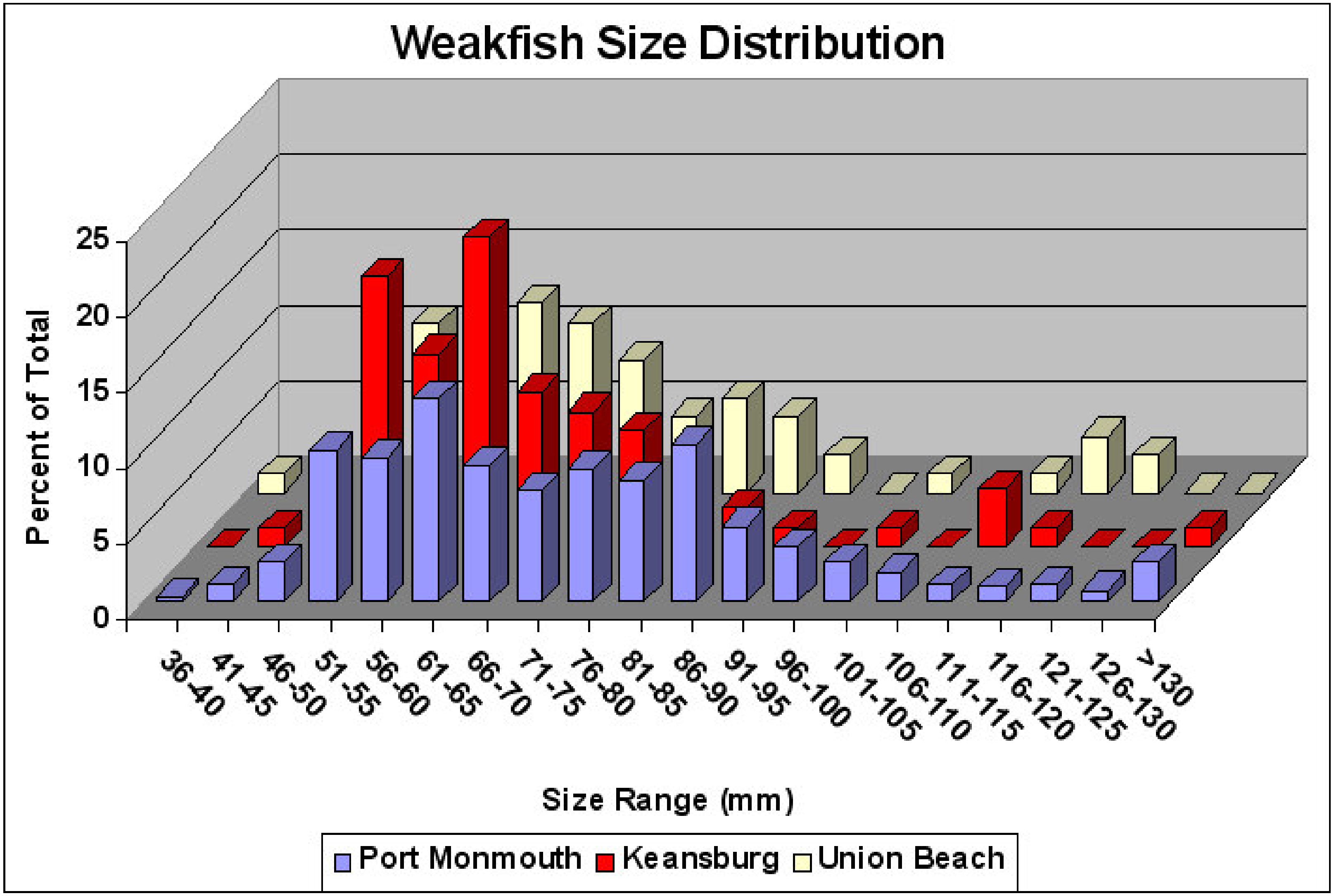


Figure 17. Size distribution of weakfish by area

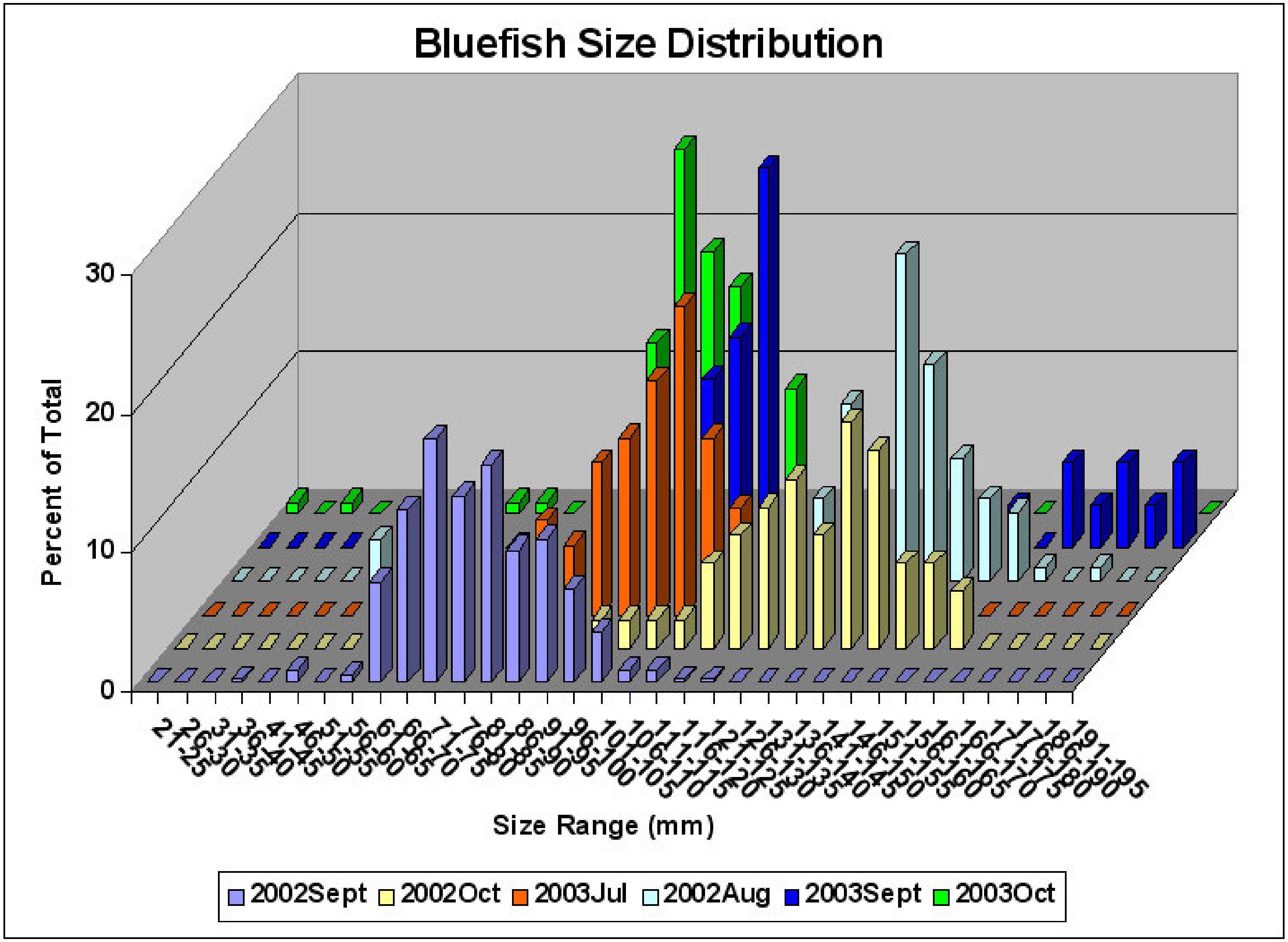


Figure 18. Size distribution of bluefish by date

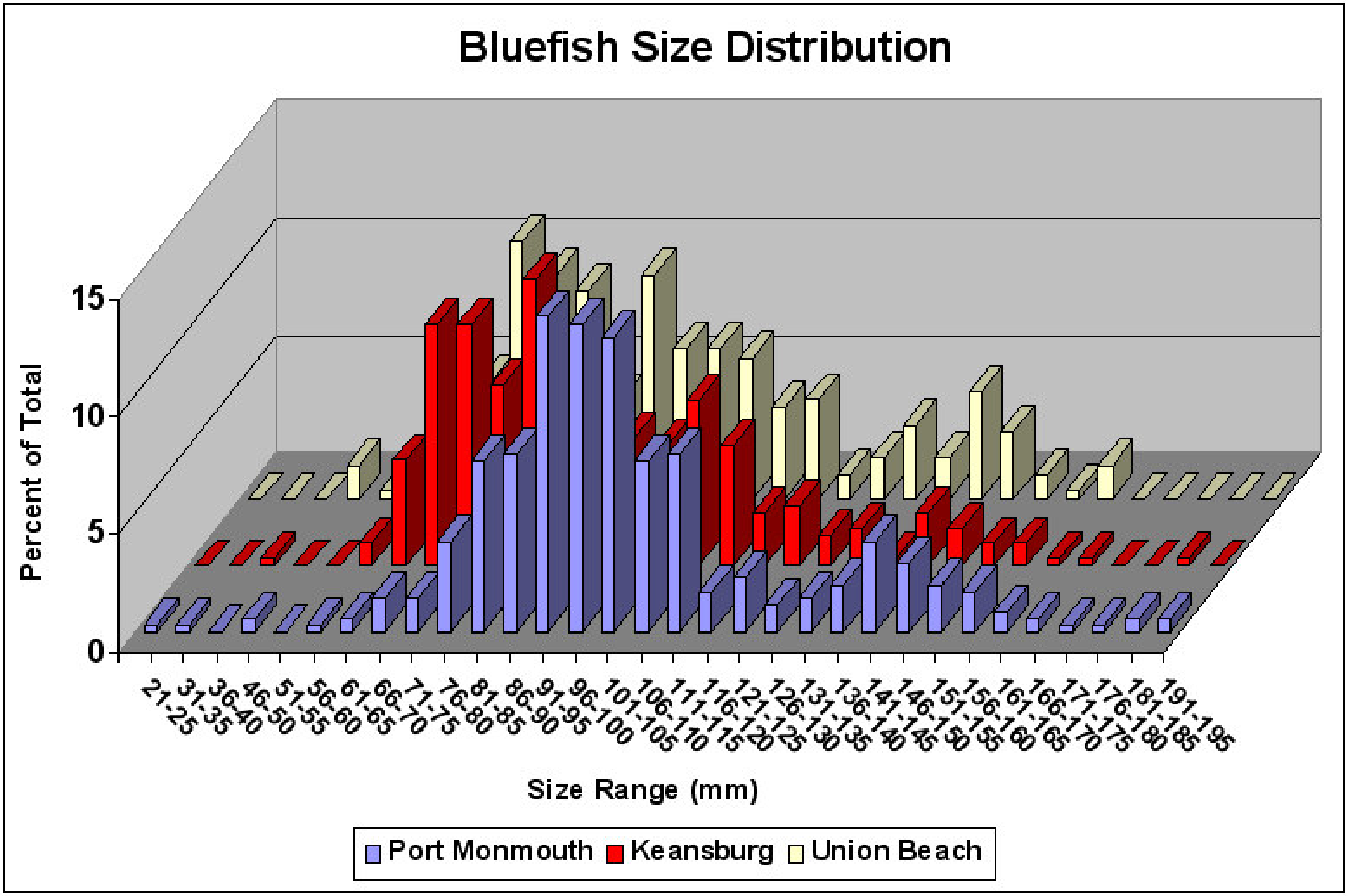


Figure 19. Size distribution of bluefish by area

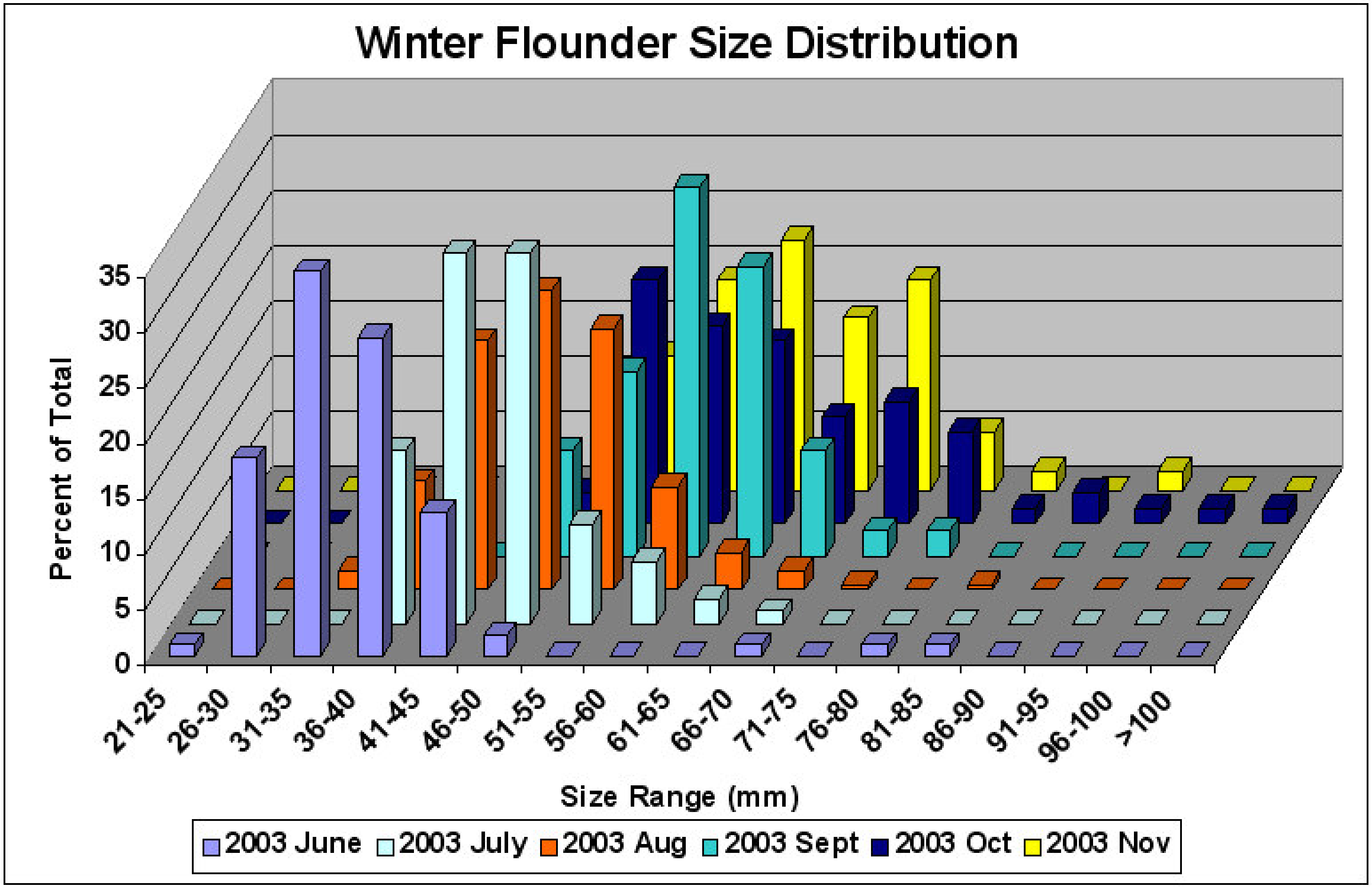


Figure 20. Size distribution of winter flounder by date

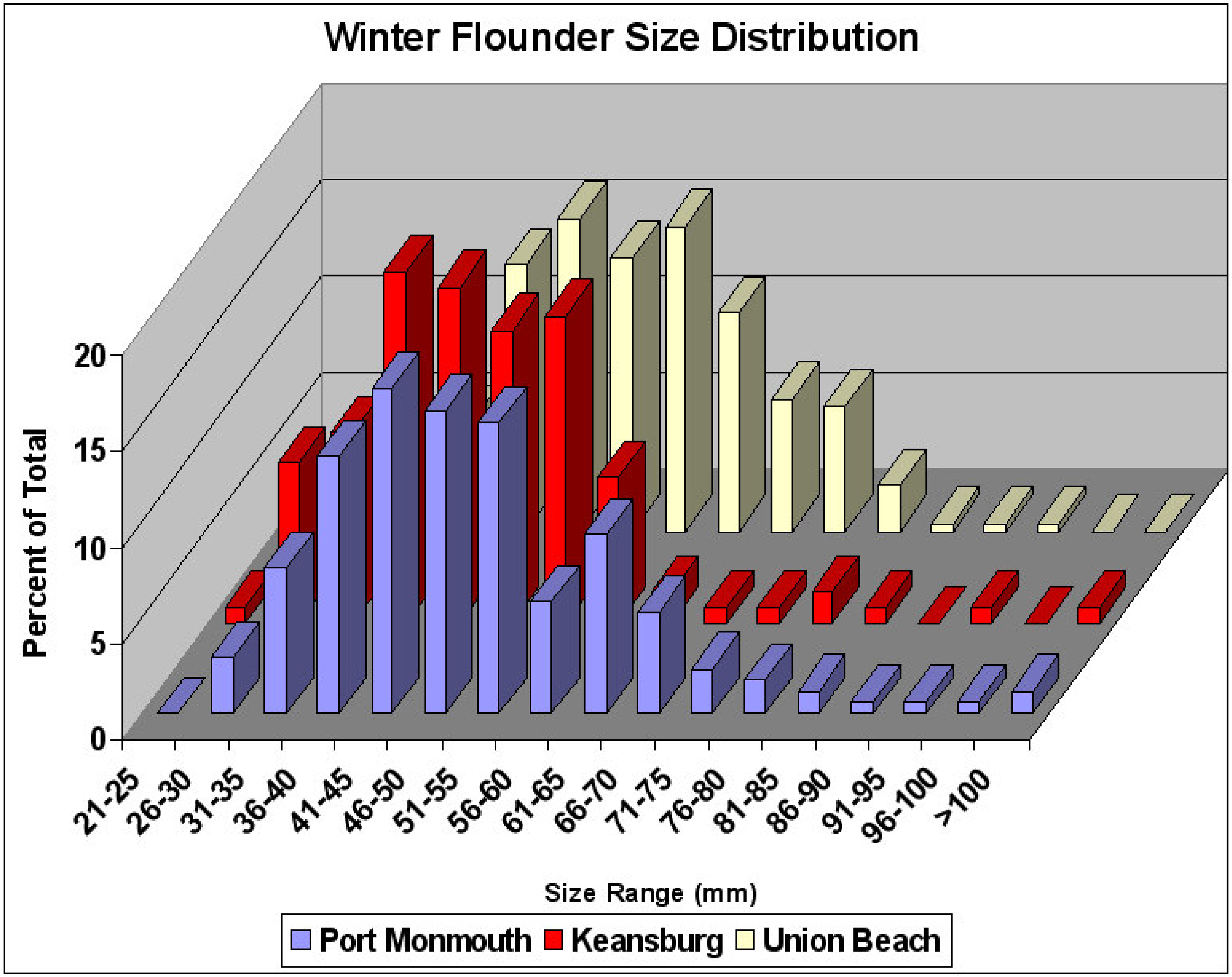


Figure 21. Size distribution of winter flounder by area

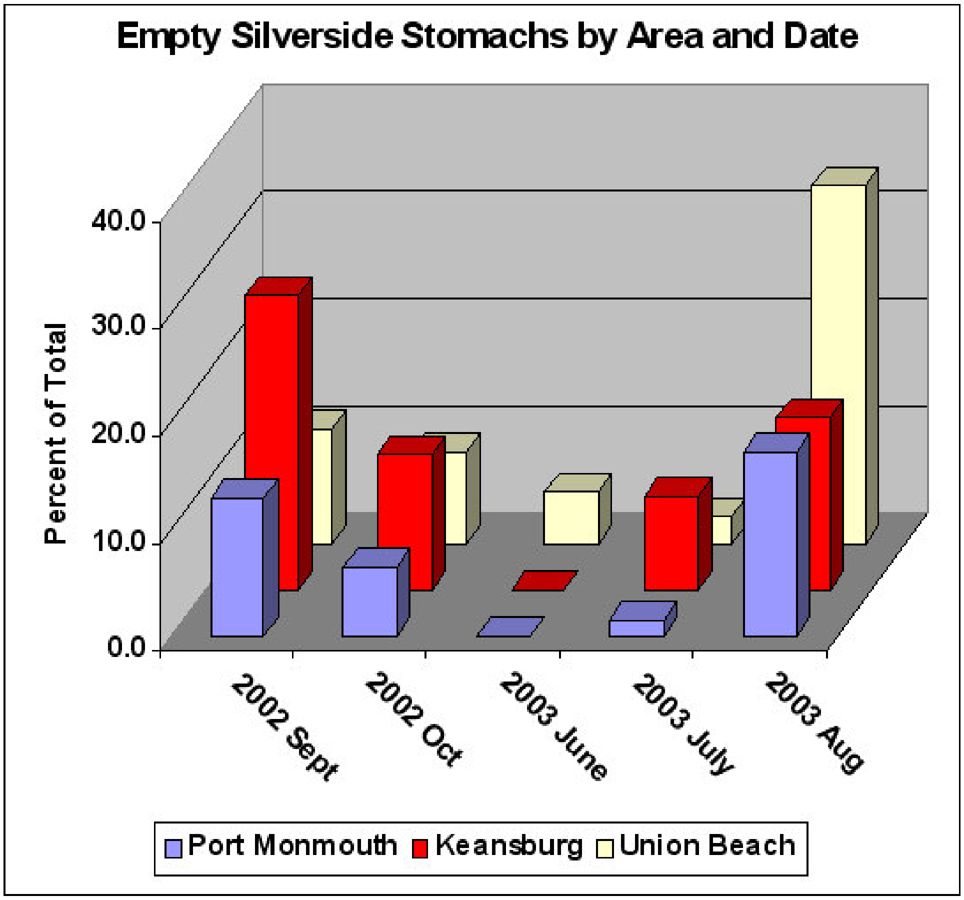


Figure 22. Empty silverside stomachs by area and date

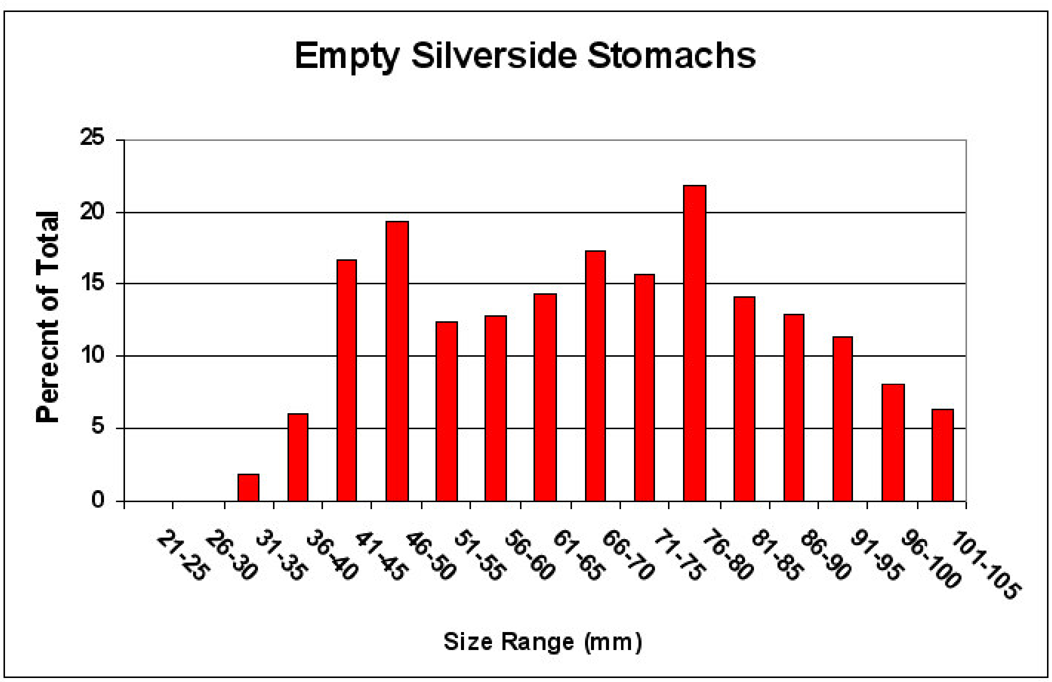


Figure 23. Empty silverside stomachs by size range

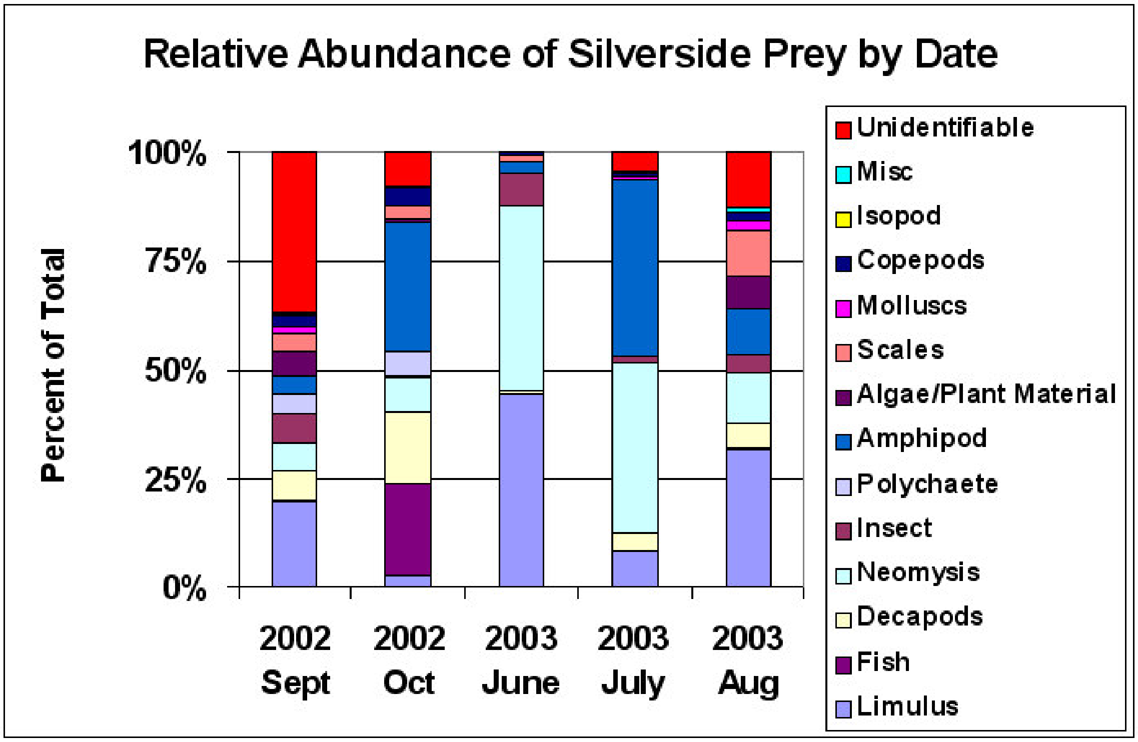


Figure 24. Relative abundance of silverside prey by date.

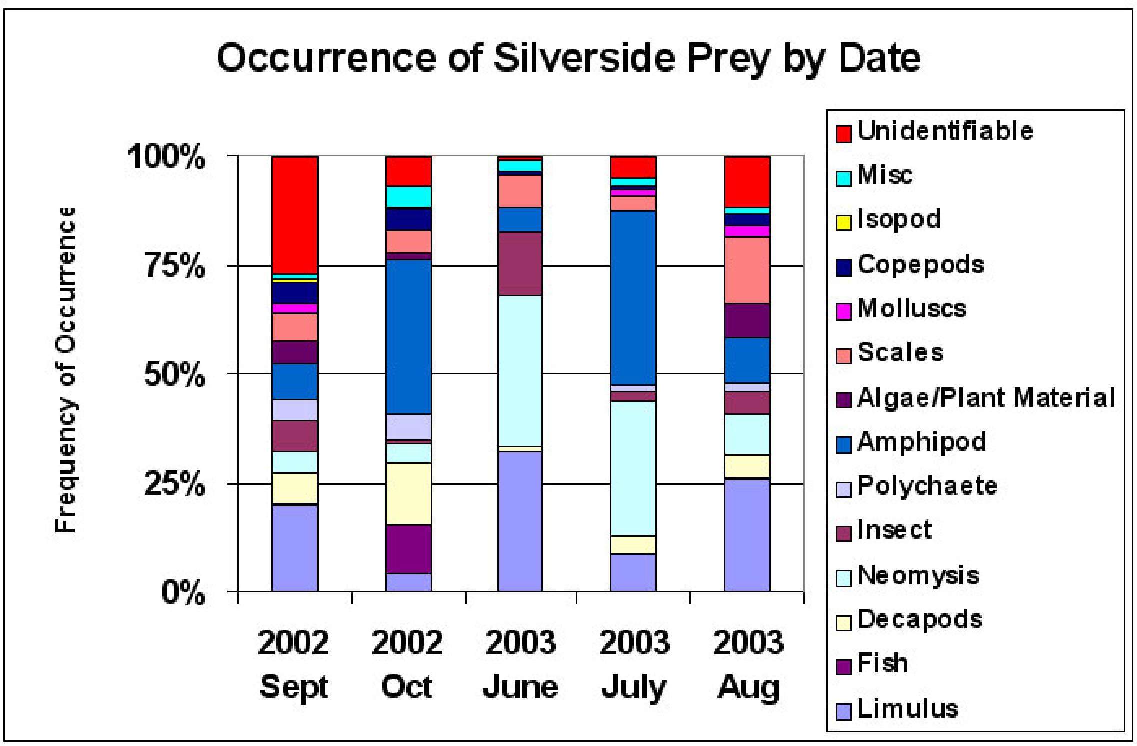


Figure 25. Frequency of occurrence of silverside prey by date

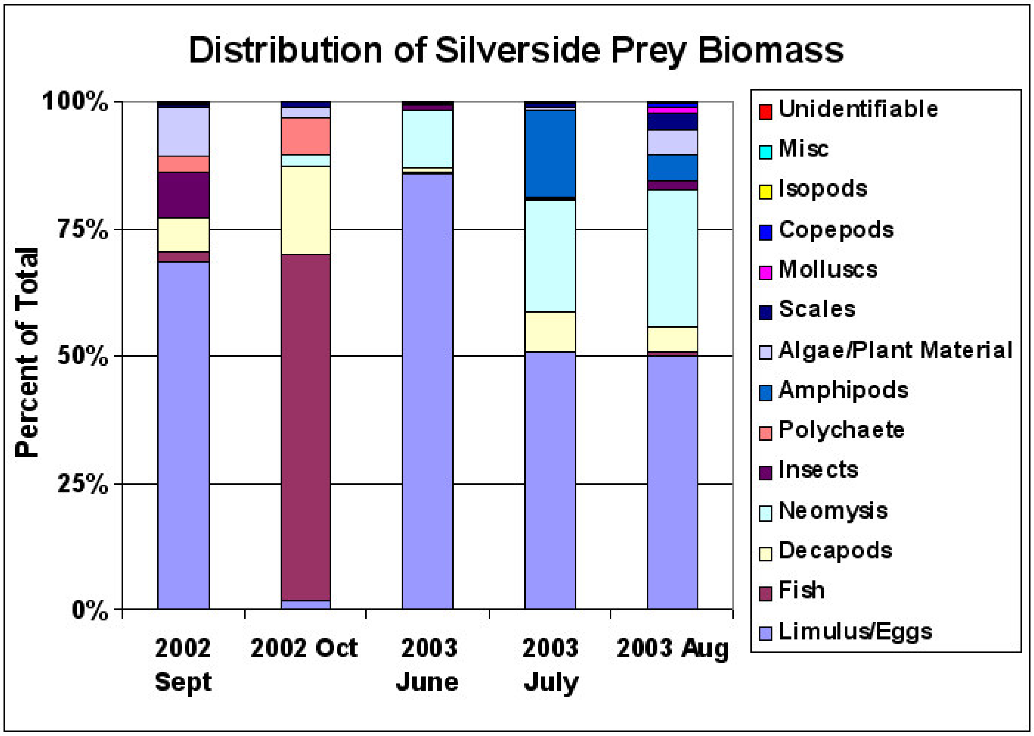


Figure 26. Distribution of silverside prey biomass by date.

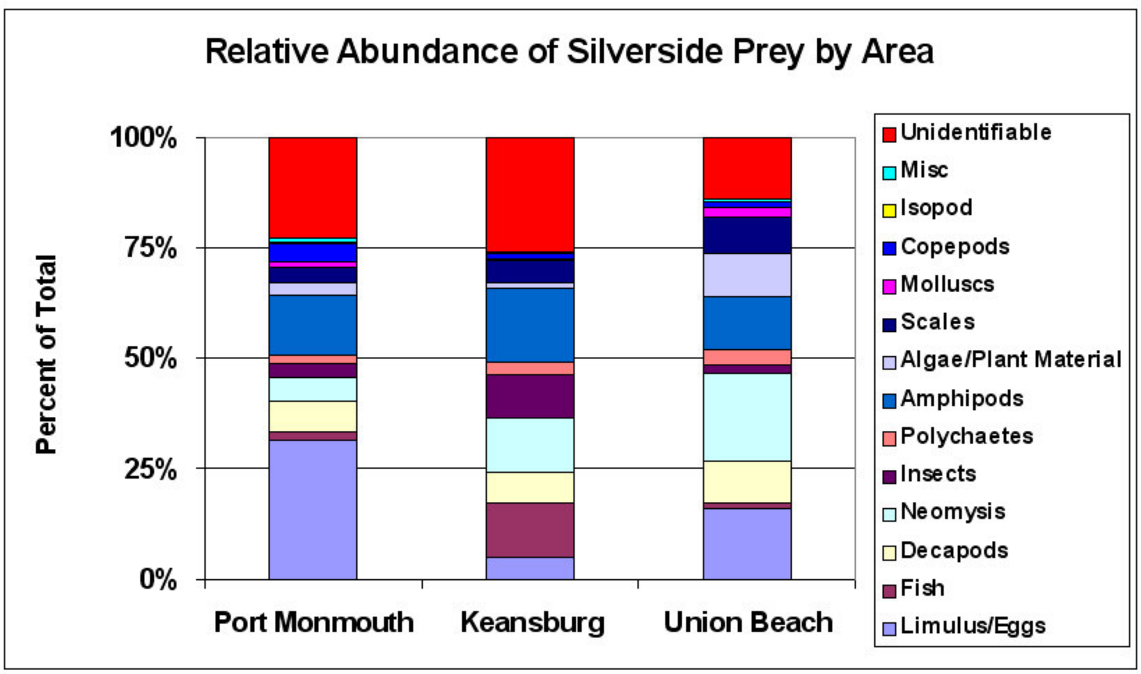


Figure 27. Relative abundance of silverside prey by area

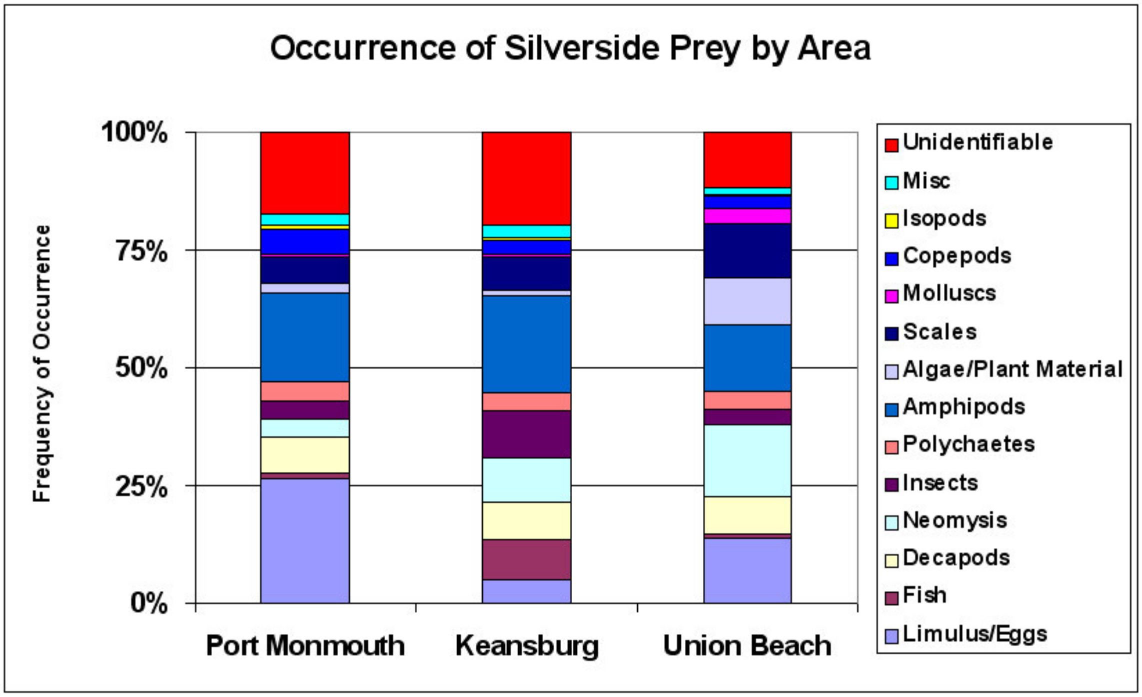


Figure 28. Frequency of occurrence of silverside prey by area

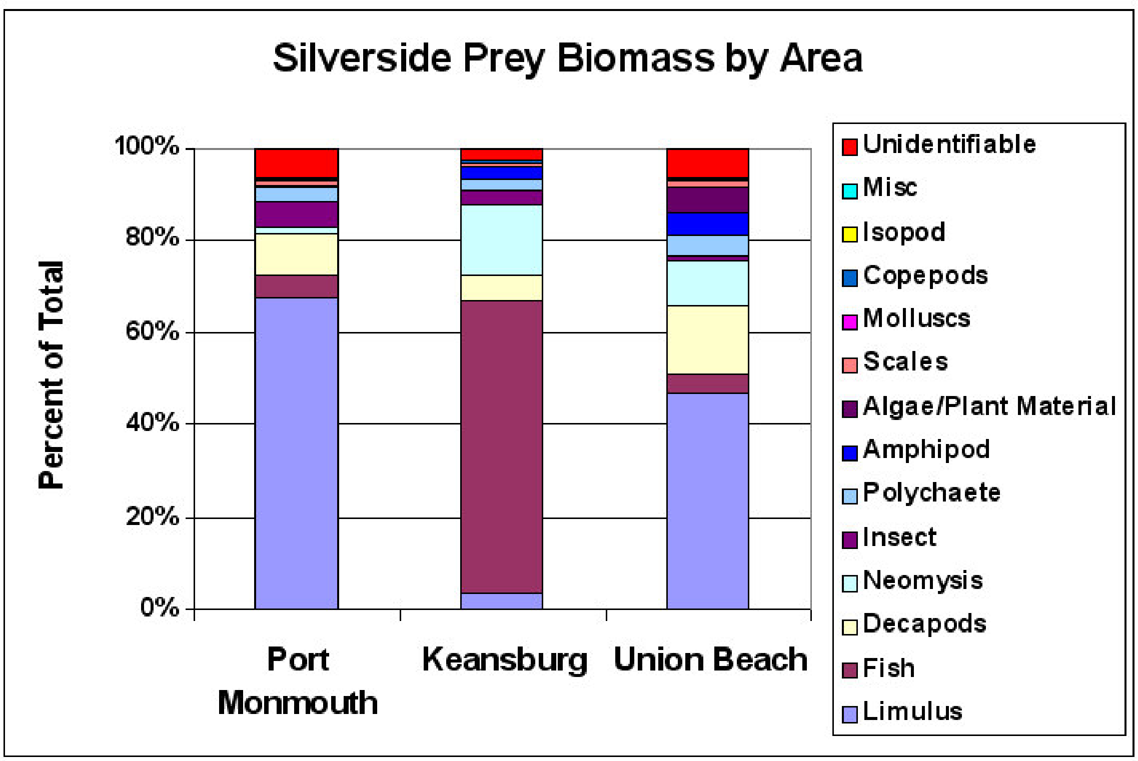


Figure 29. Silverside prey biomass by area

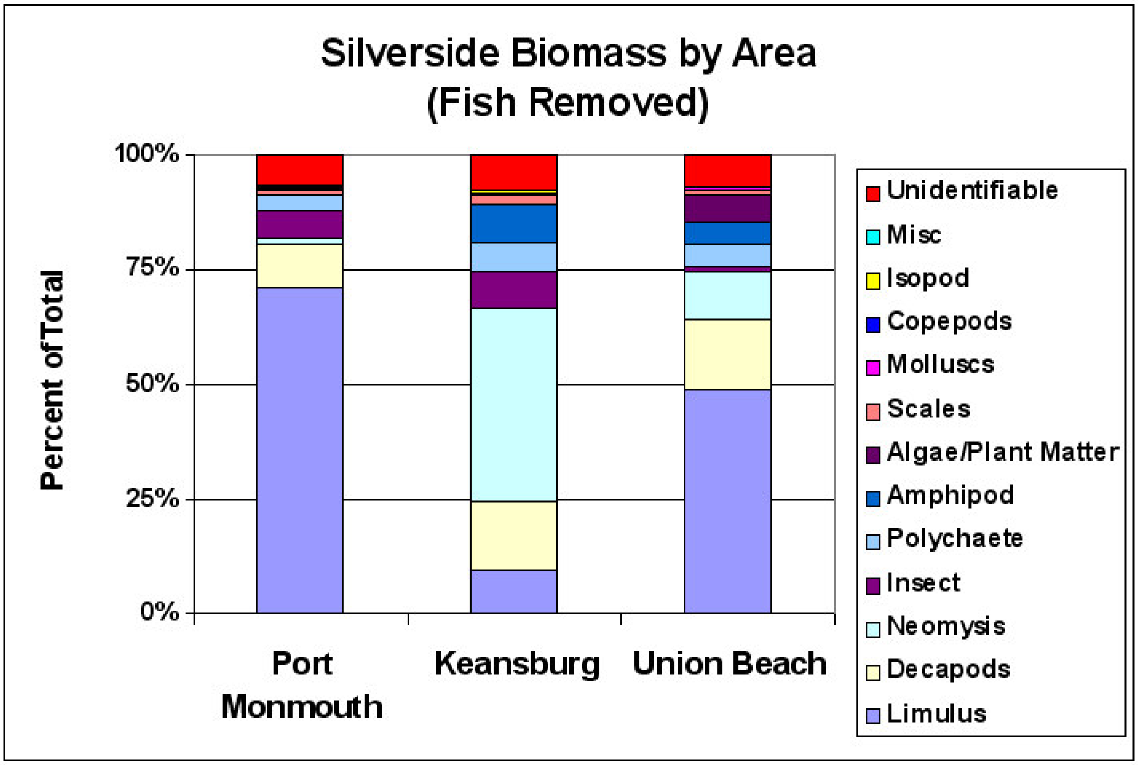


Figure 30. Silverside prey biomass by area after removal of fish component

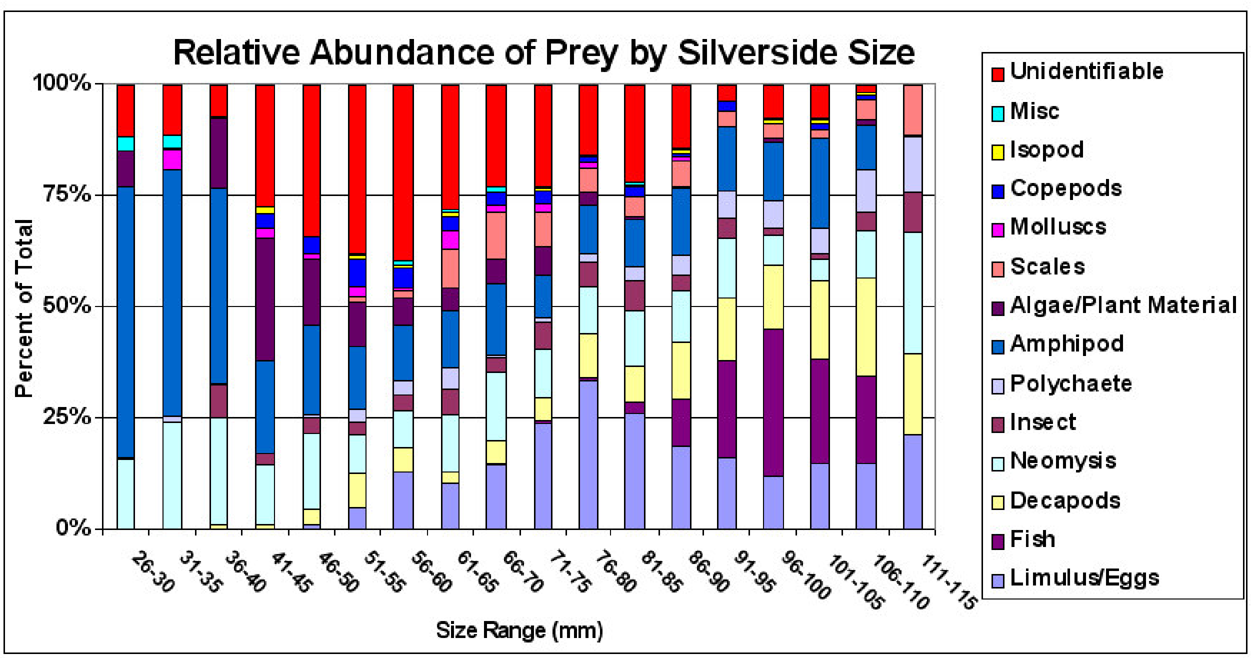


Figure 31. Relative abundance of silverside prey by size range

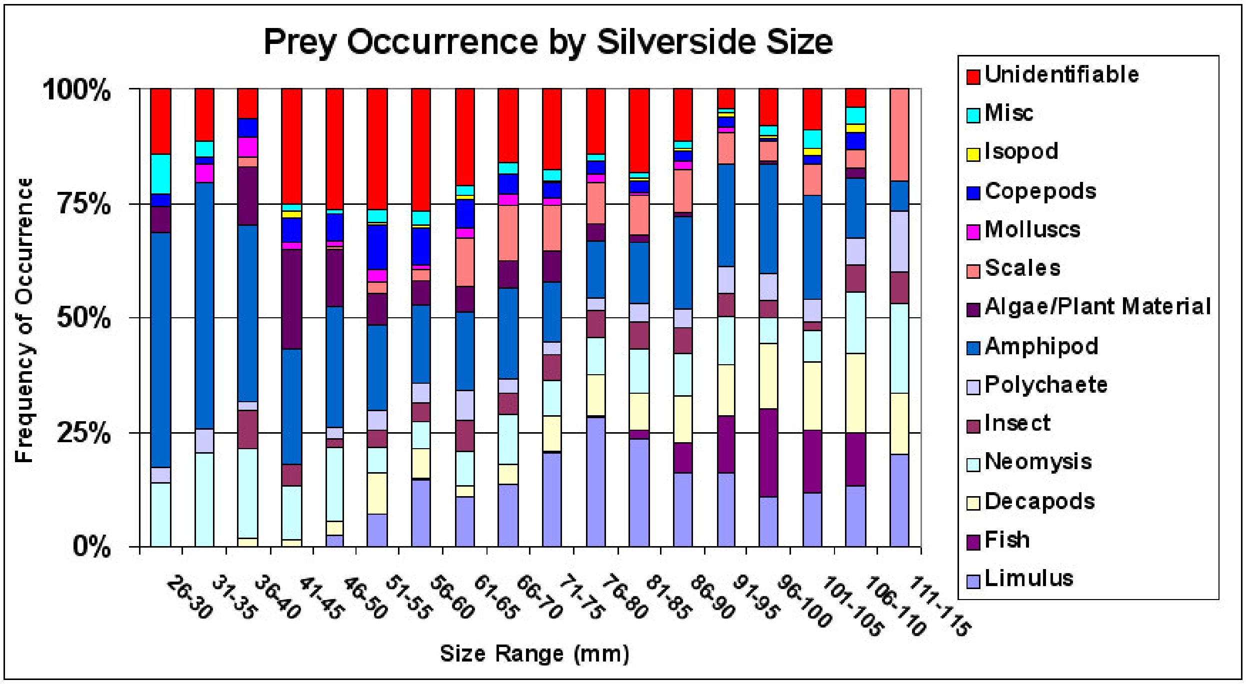


Figure 32. Frequency of occurrence of silverside prey by size range

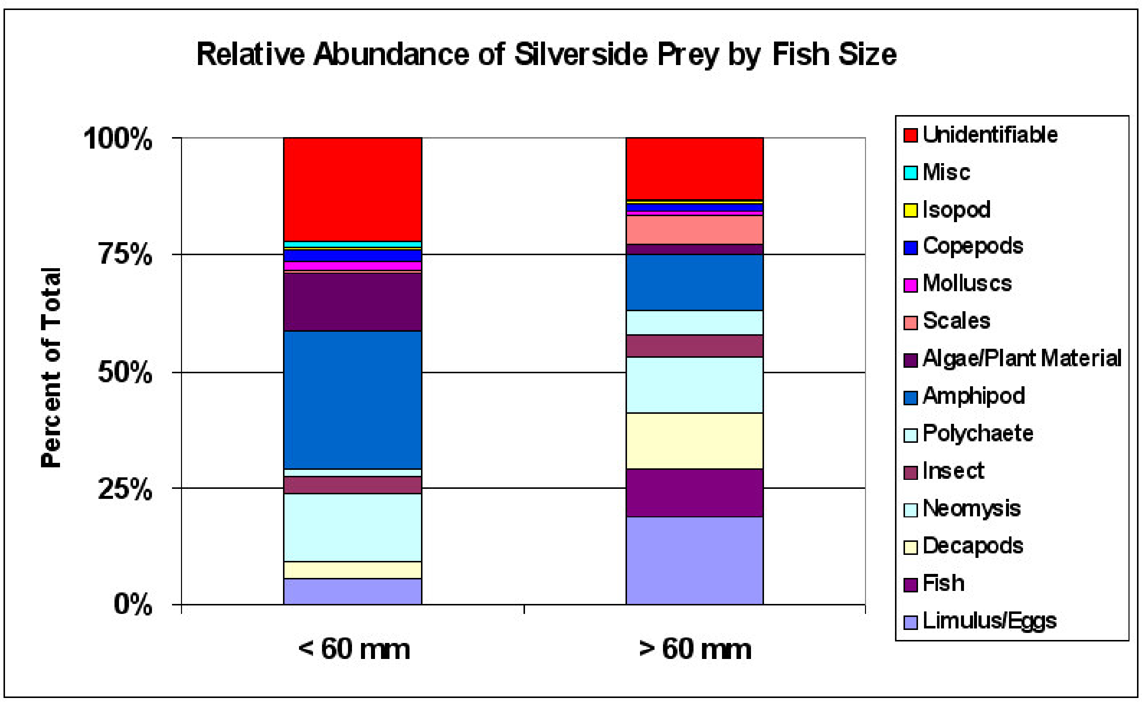


Figure 33. Relative abundance of silverside prey among large and small fishes

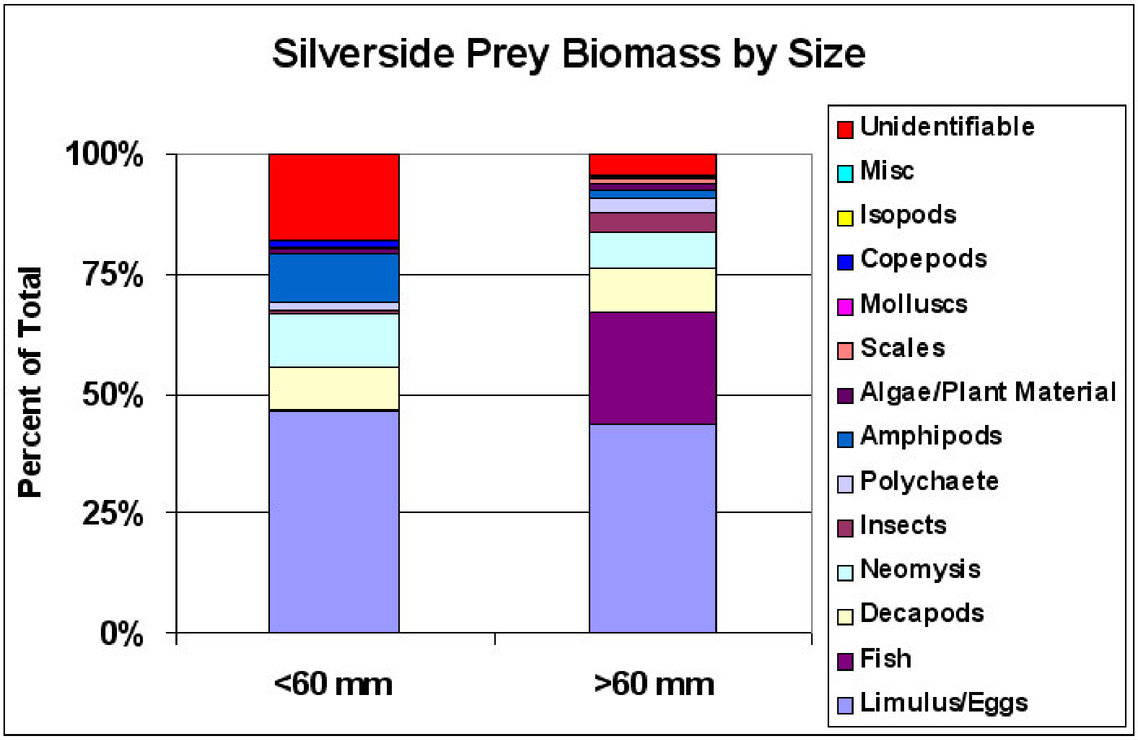


Figure 34. Silverside prey biomass among large and small fishes

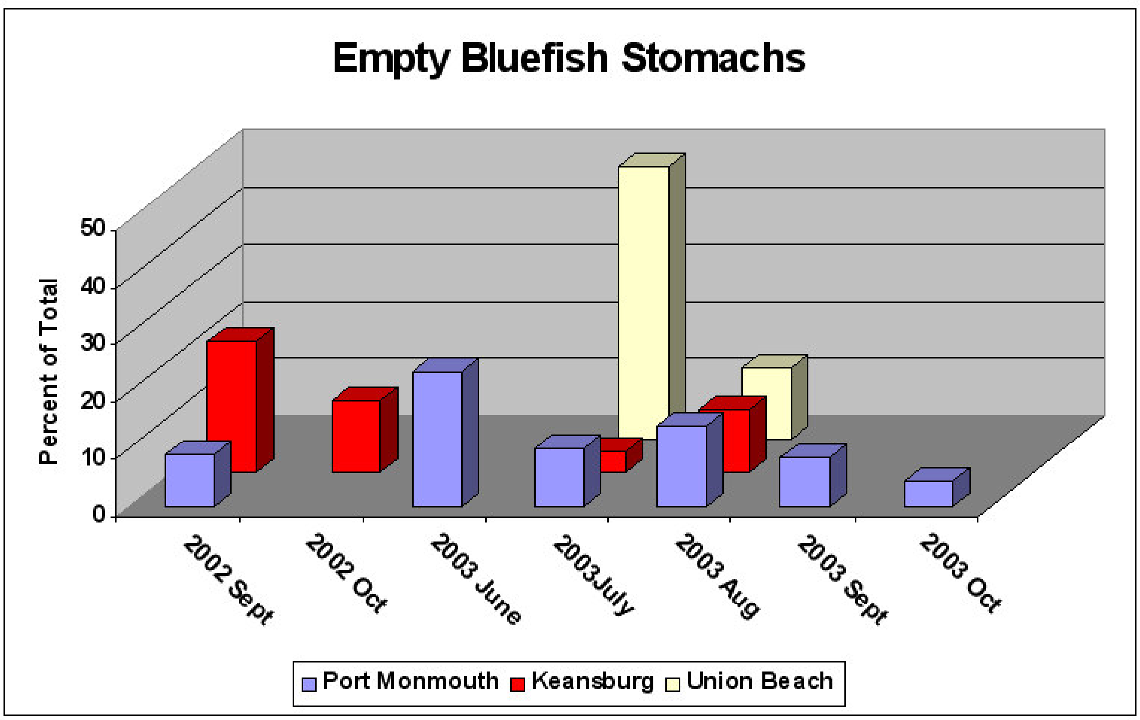


Figure 35. Empty bluefish stomachs by area and date

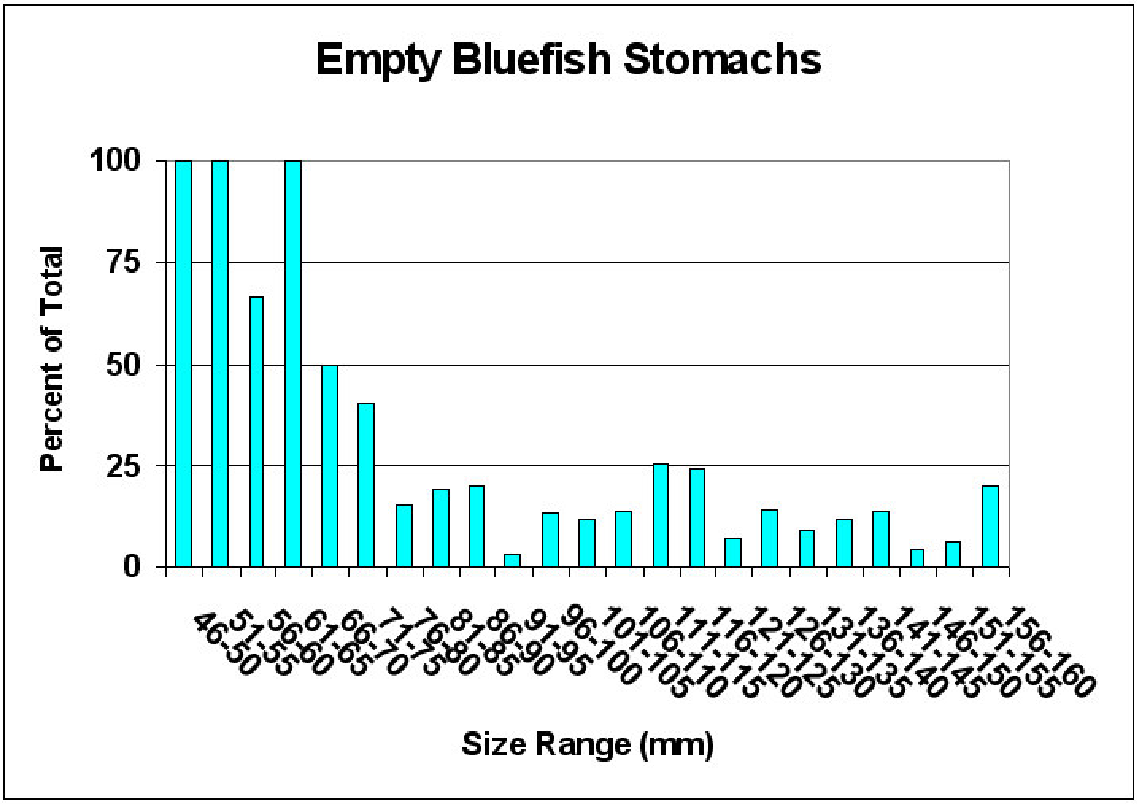


Figure 36. Empty bluefish stomachs size range

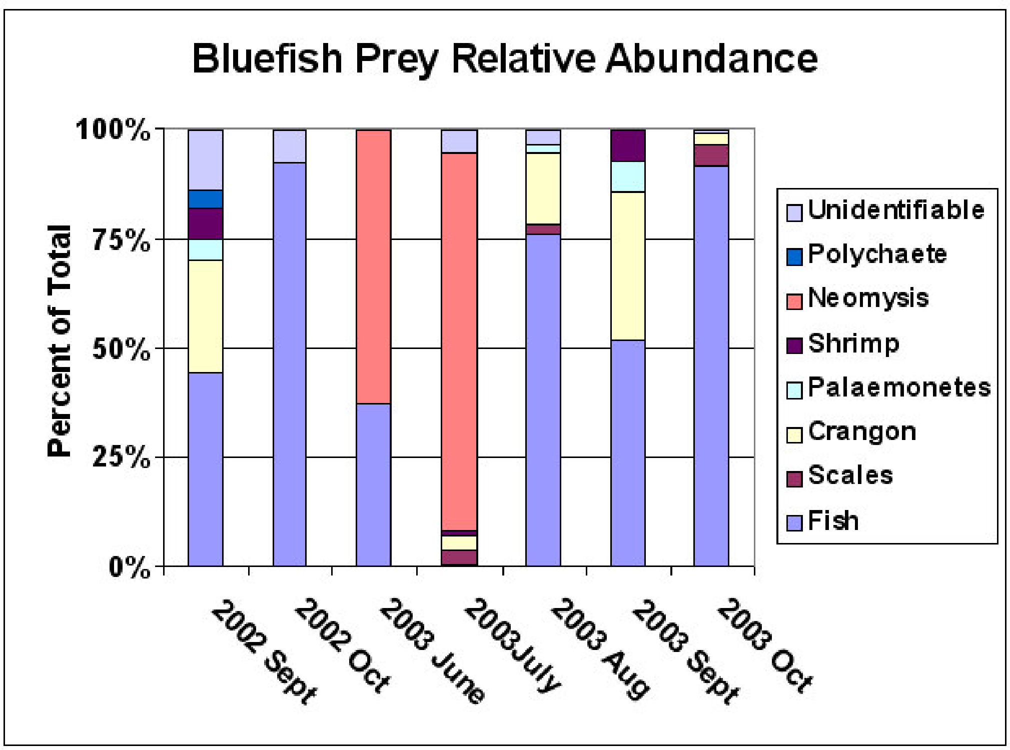


Figure 37. Relative abundance of bluefish prey items by date

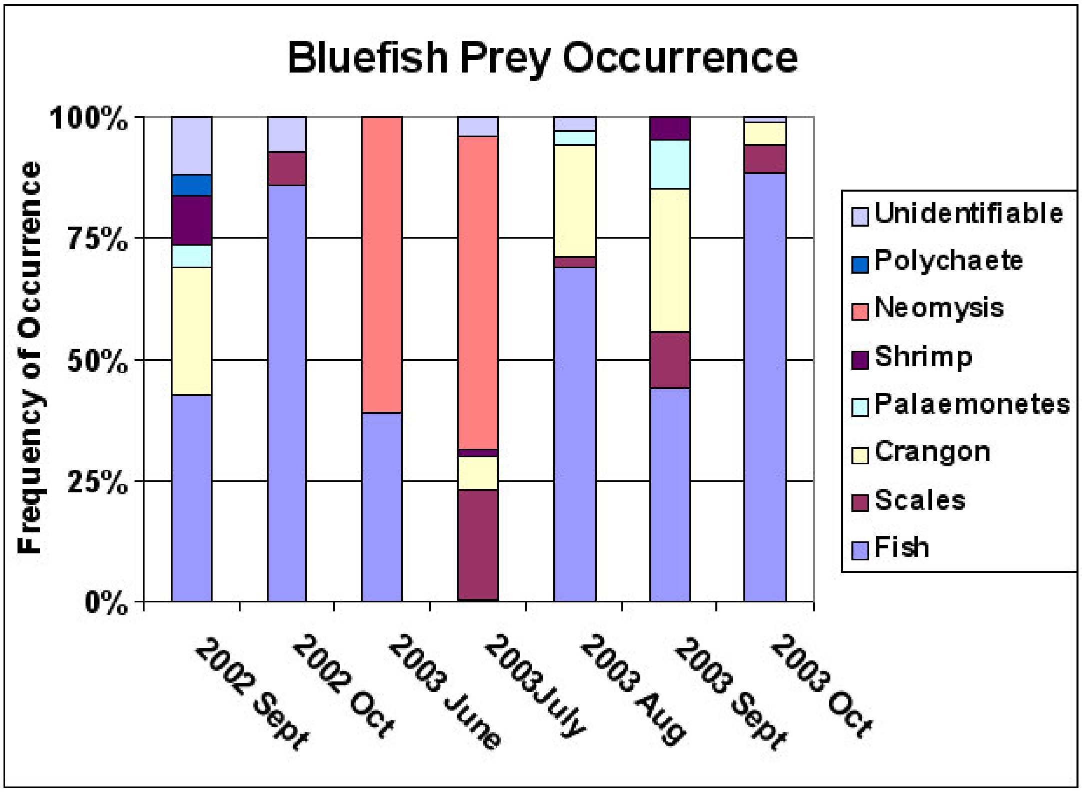


Figure 38. Frequency of occurrence of bluefish prey items by date.

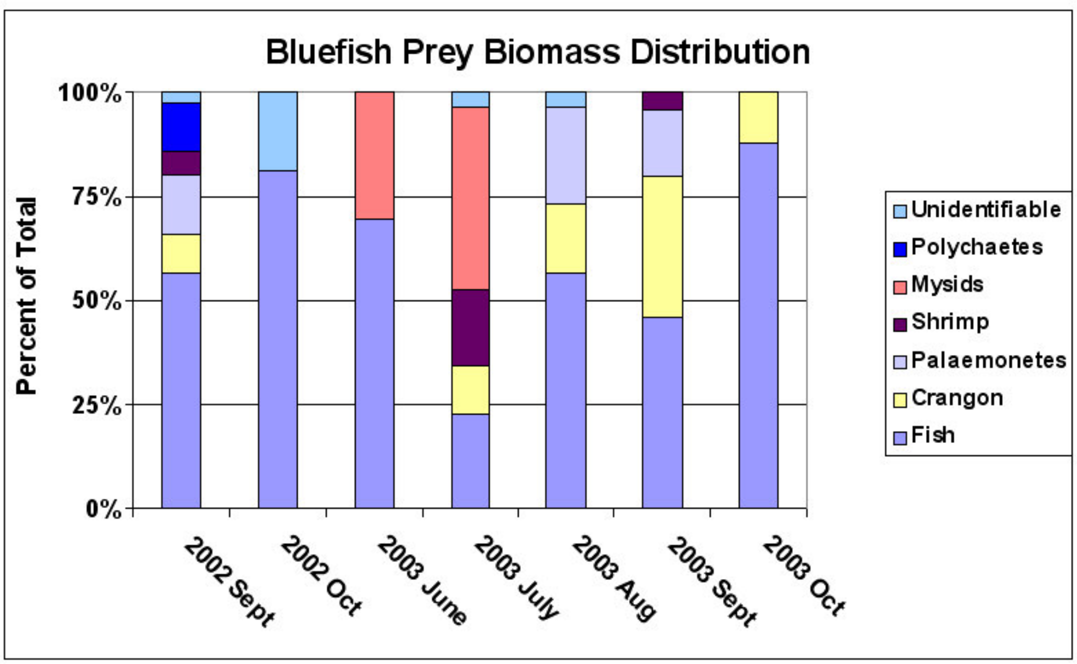


Figure 39. Distribution of bluefish prey biomass by date

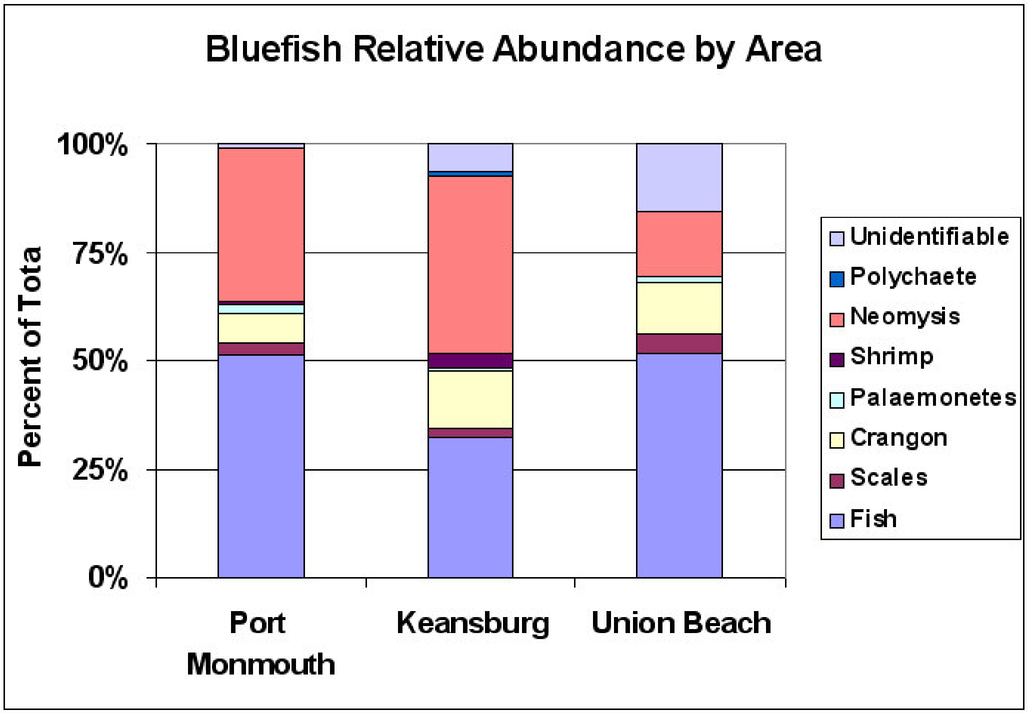


Figure 40. Relative abundance of bluefish prey by area

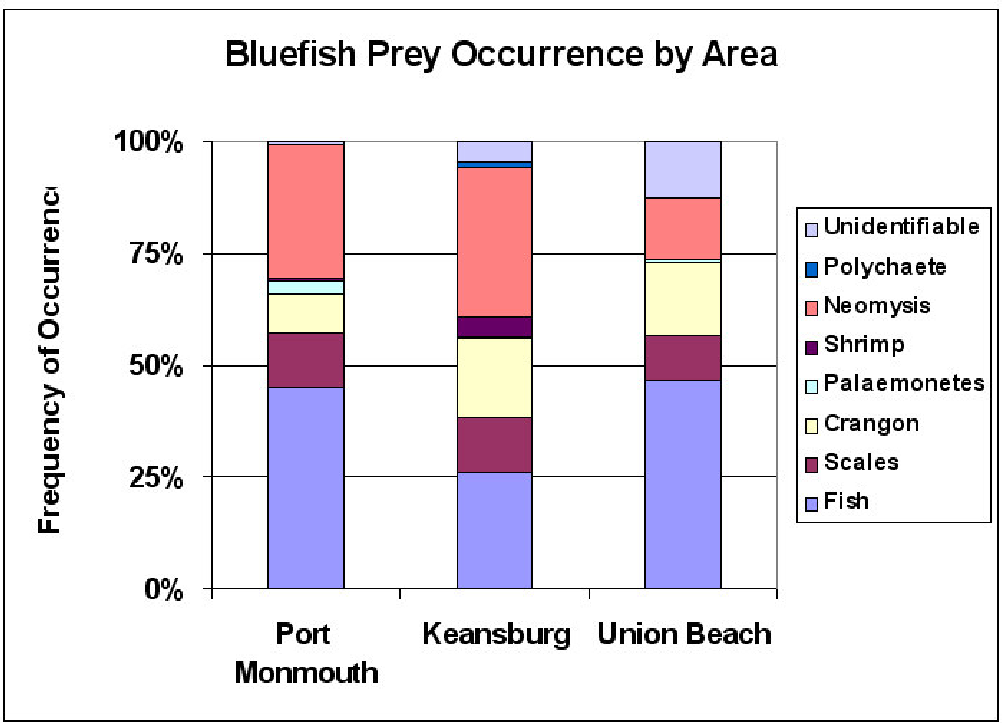


Figure 41. Frequency of occurrence of bluefish prey by area

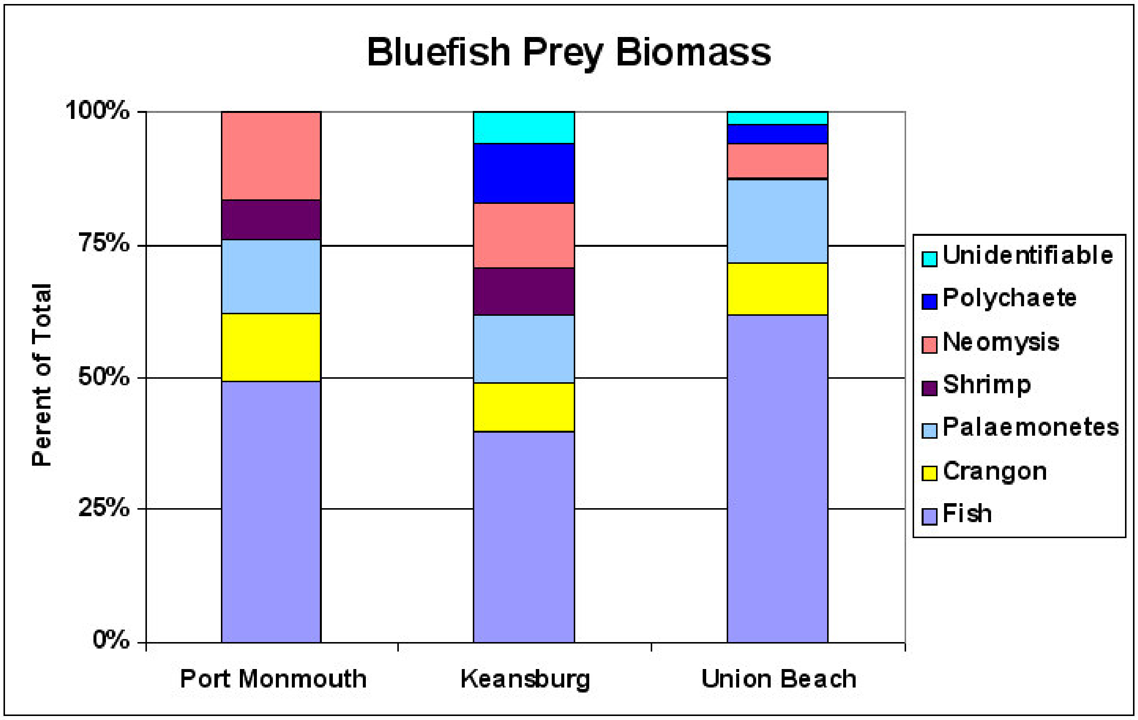


Figure 42. Biomass distribution of bluefish prey by area

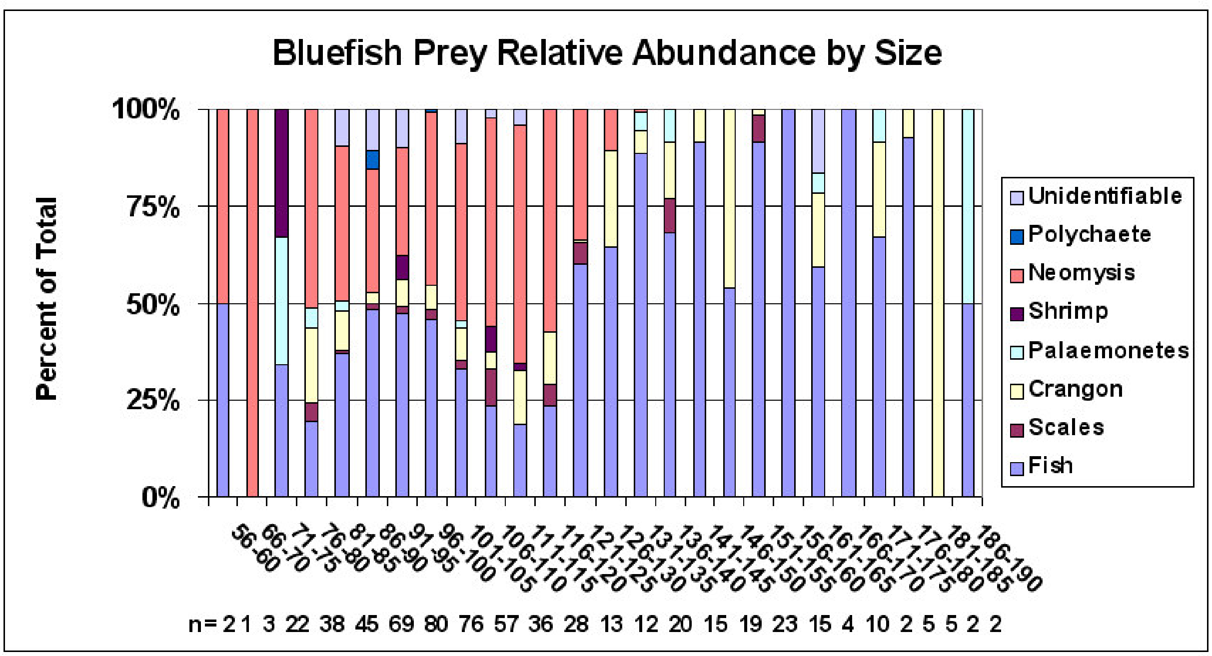


Figure 43. Relative abundance of bluefish prey by size range

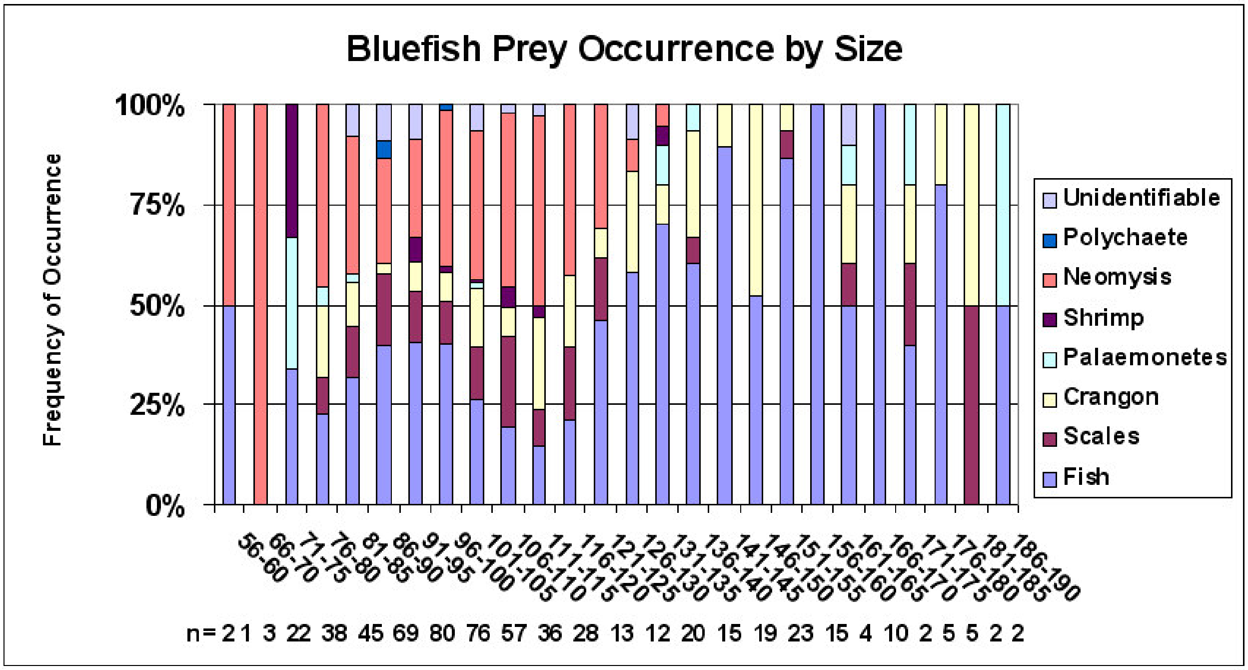


Figure 44. Frequency of occurrence of bluefish prey by size range

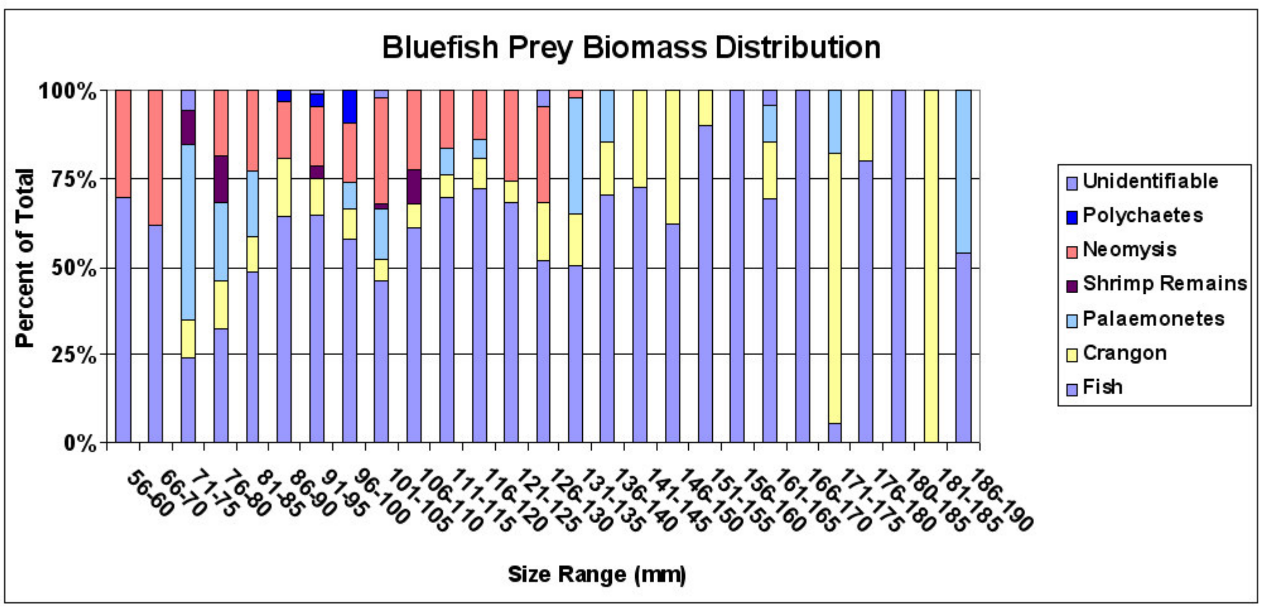


Figure 45. Biomass distribution of bluefish prey by size range

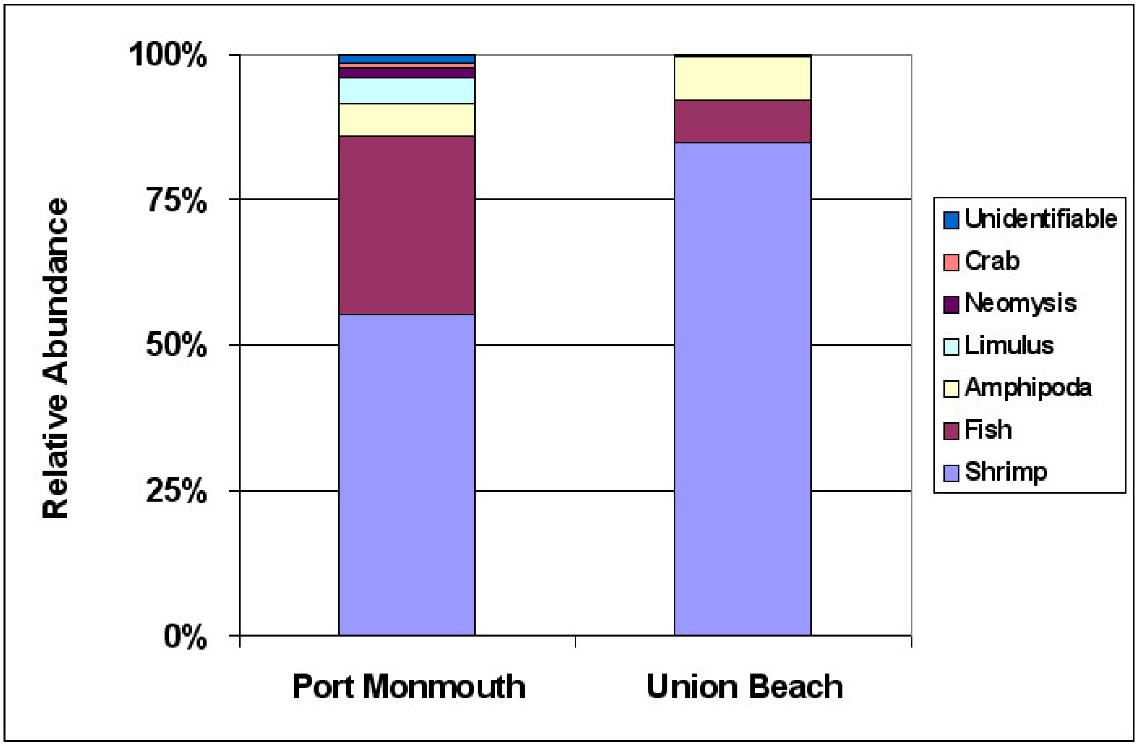


Figure 46. Relative abundance of weakfish prey by area

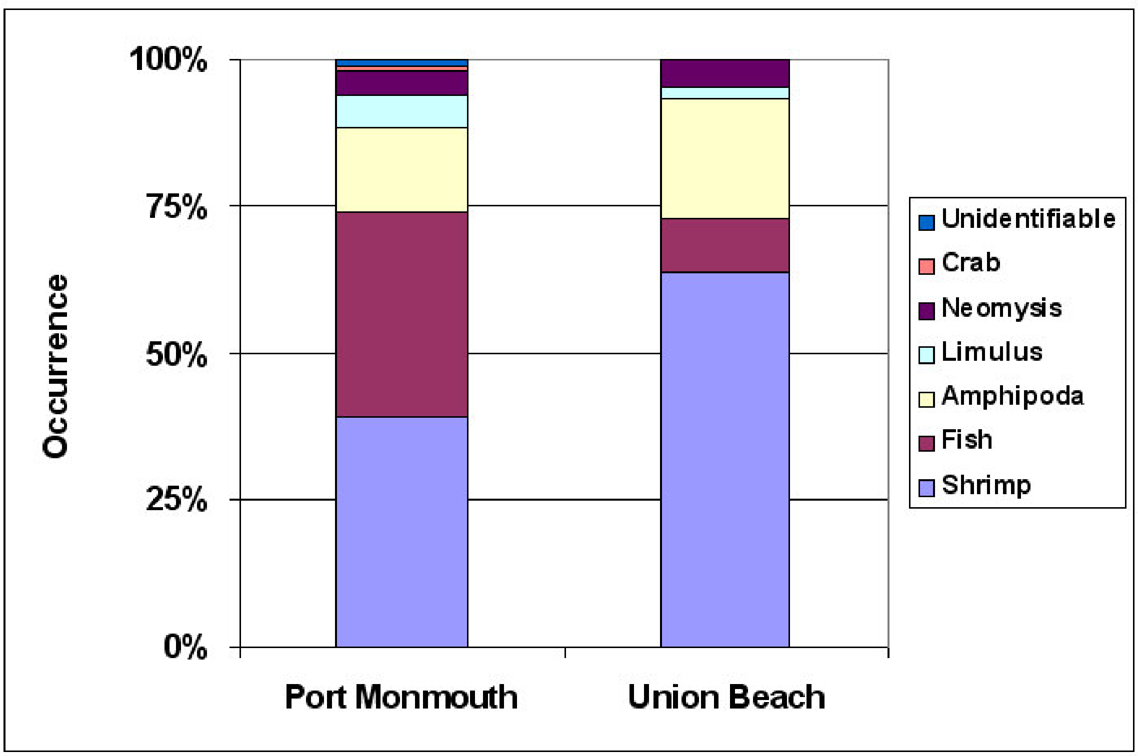


Figure 47. Frequency of occurrence of weakfish prey by area

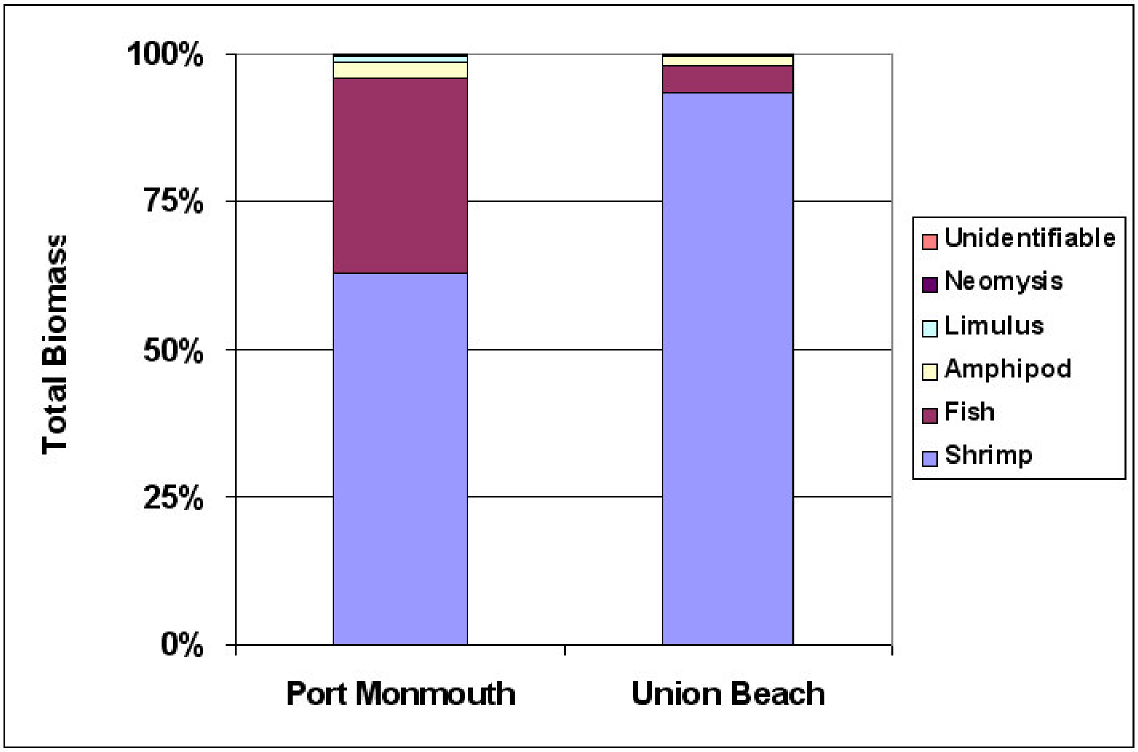


Figure 48. Biomass distribution of weakfish prey by area

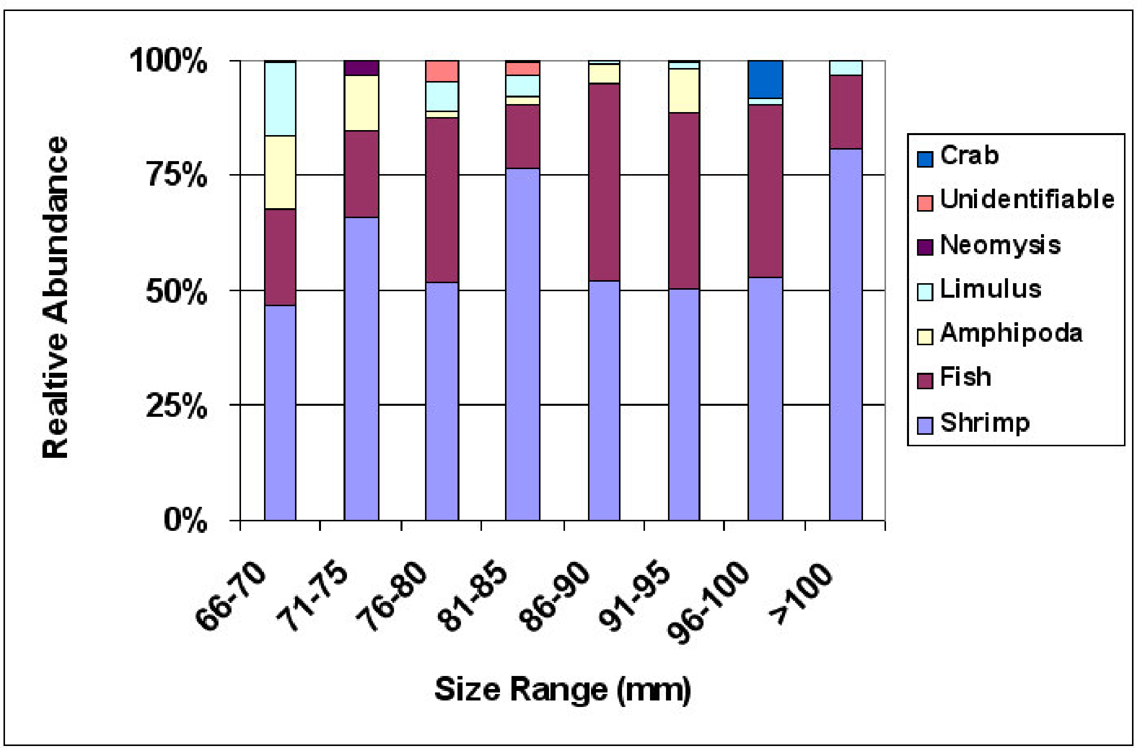


Figure 49. Relative abundance of weakfish prey by size

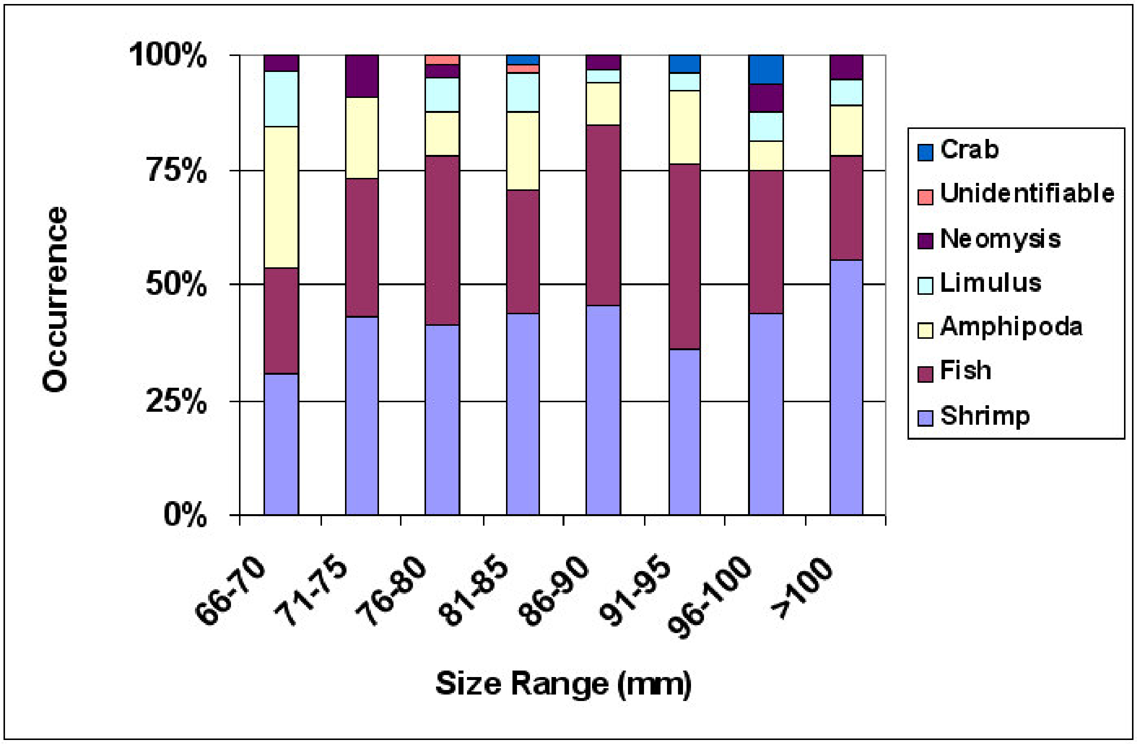


Figure 50. Occurrence of weakfish prey by size

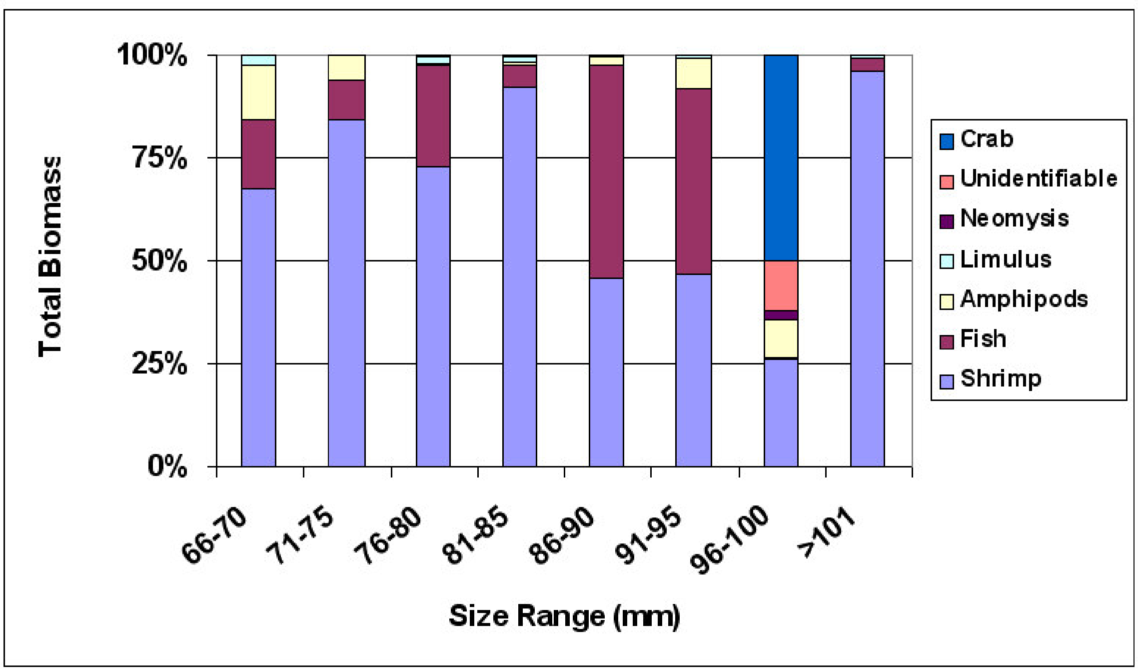


Figure 51. Biomass distribution of weakfish prey by size

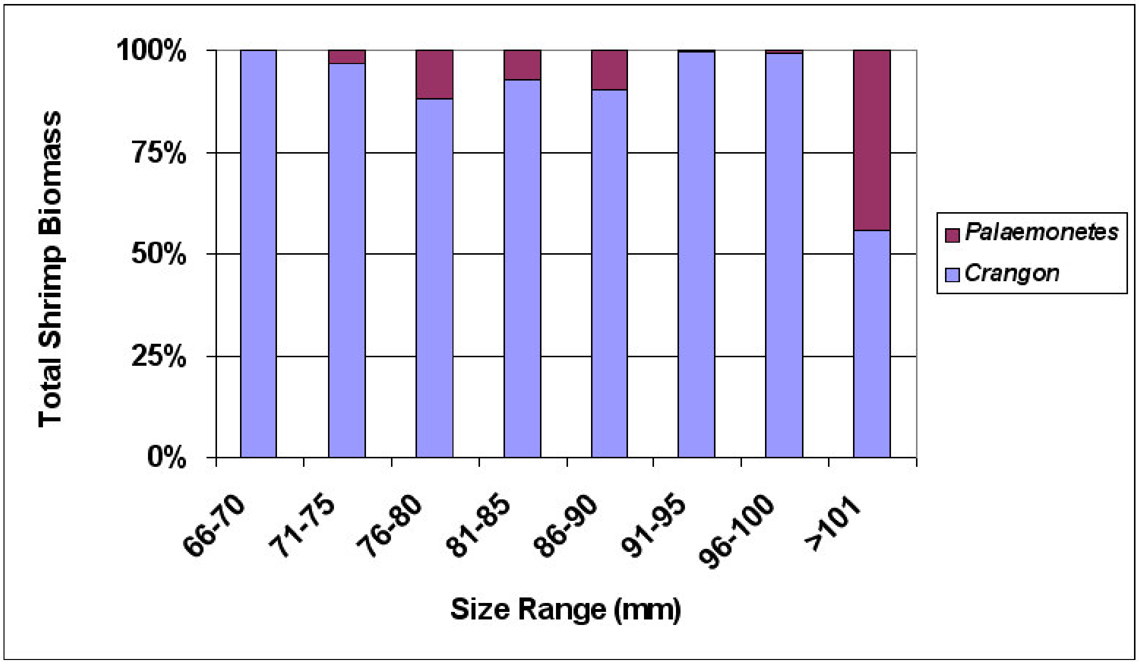


Figure 52. Biomass distribution of weakfish shrimp prey by size

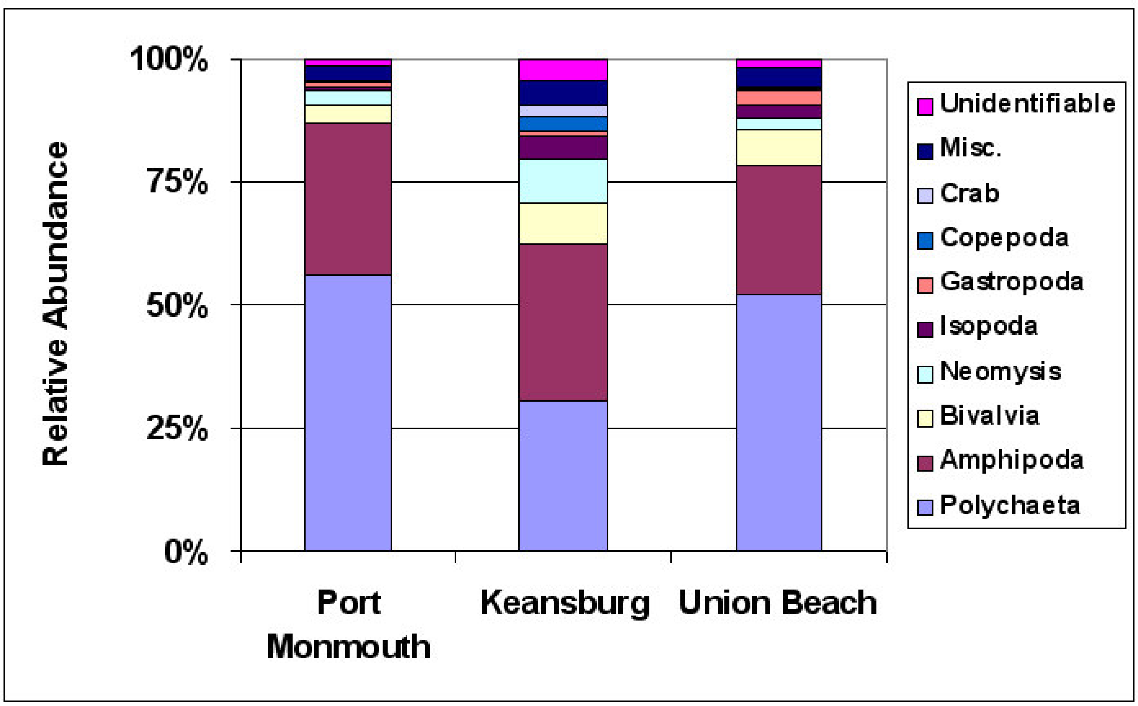


Figure 53. Relative abundance of winter flounder prey by area

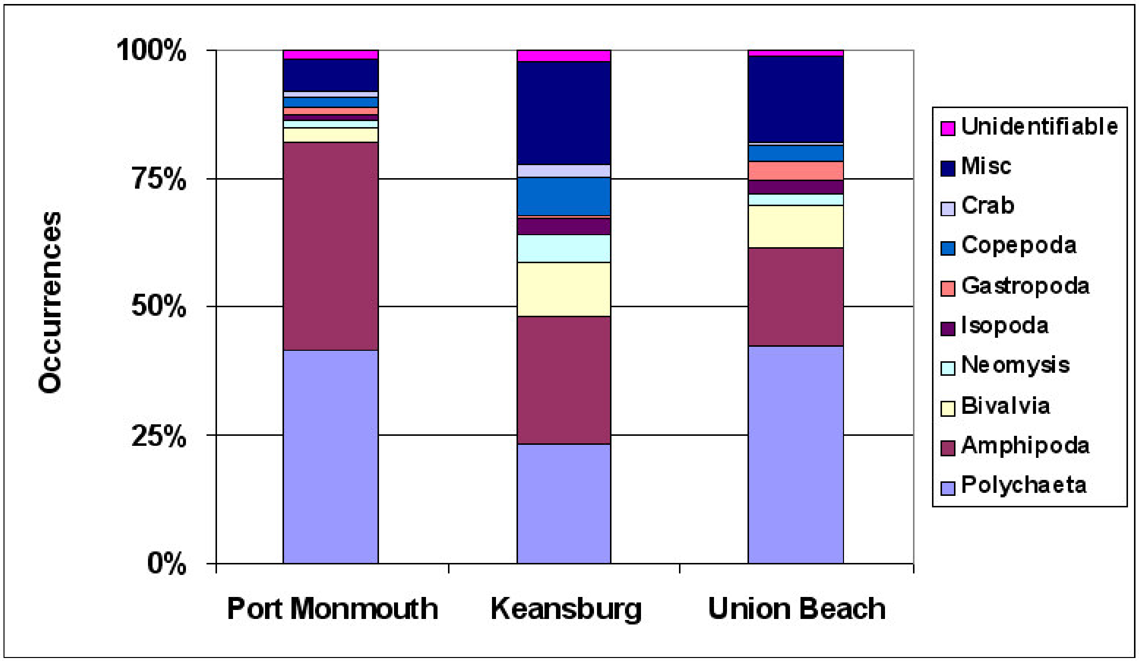


Figure 54. Occurrence of winter flounder prey by area

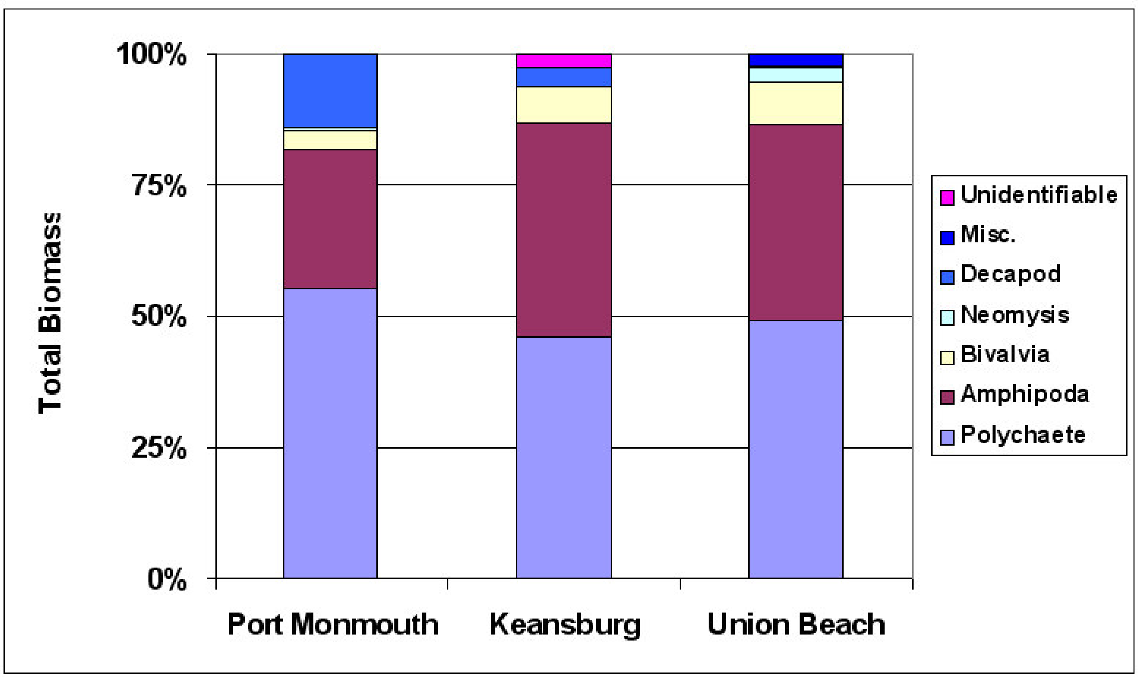


Figure 55. Biomass distribution of winter flounder prey by area

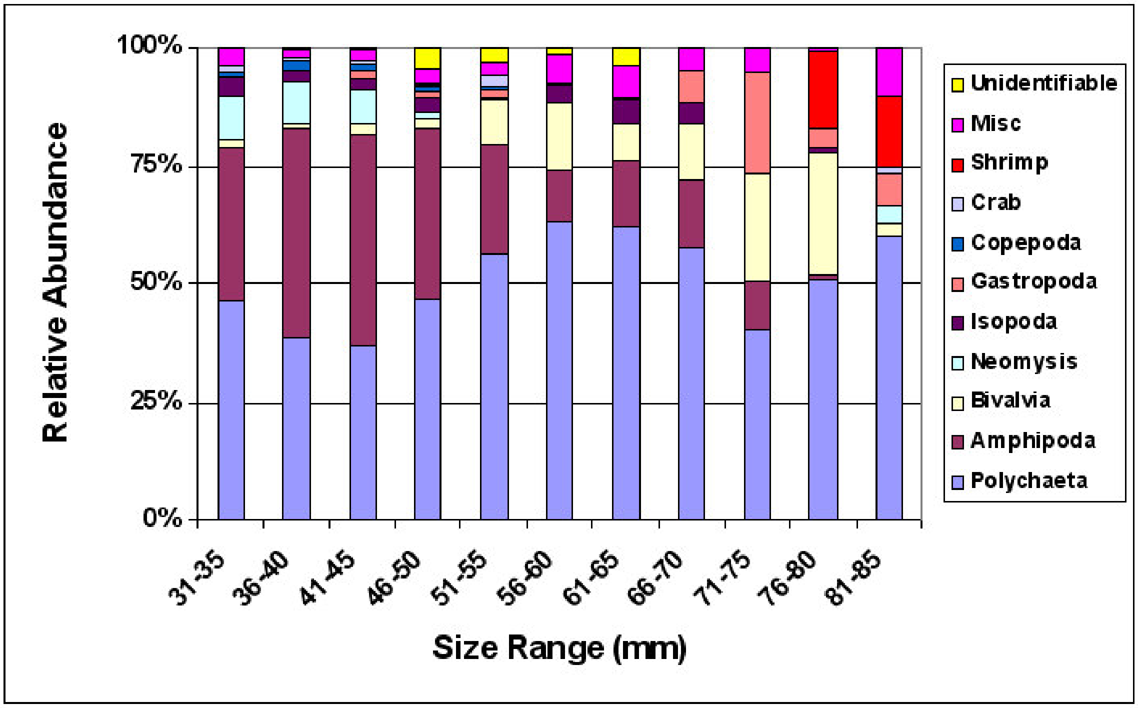


Figure 56. Relative abundance of winter flounder prey by size

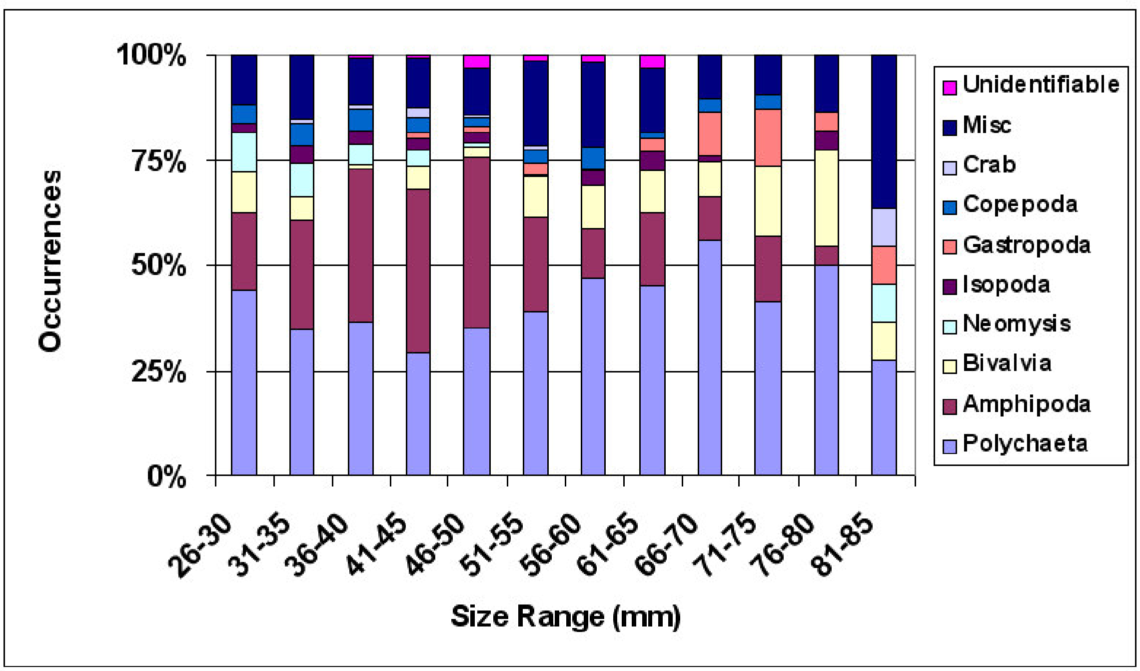


Figure 57. Occurrence of winter flounder prey by size

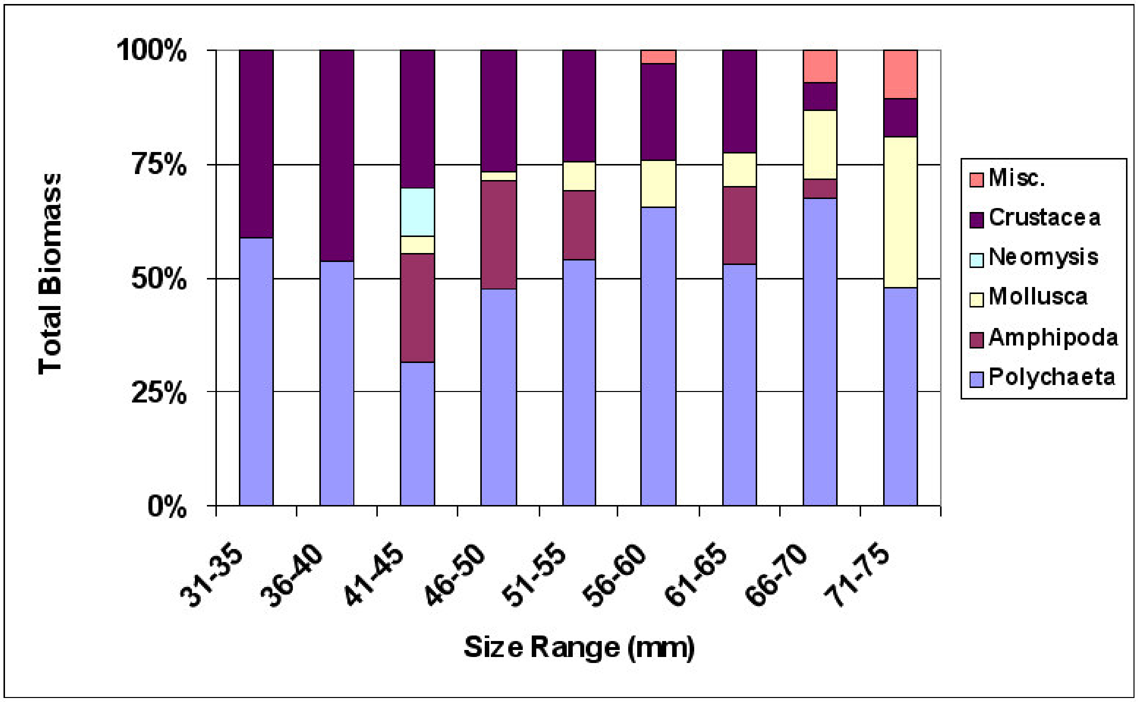


Figure 58. Biomass distribution of winter flounder prey by size

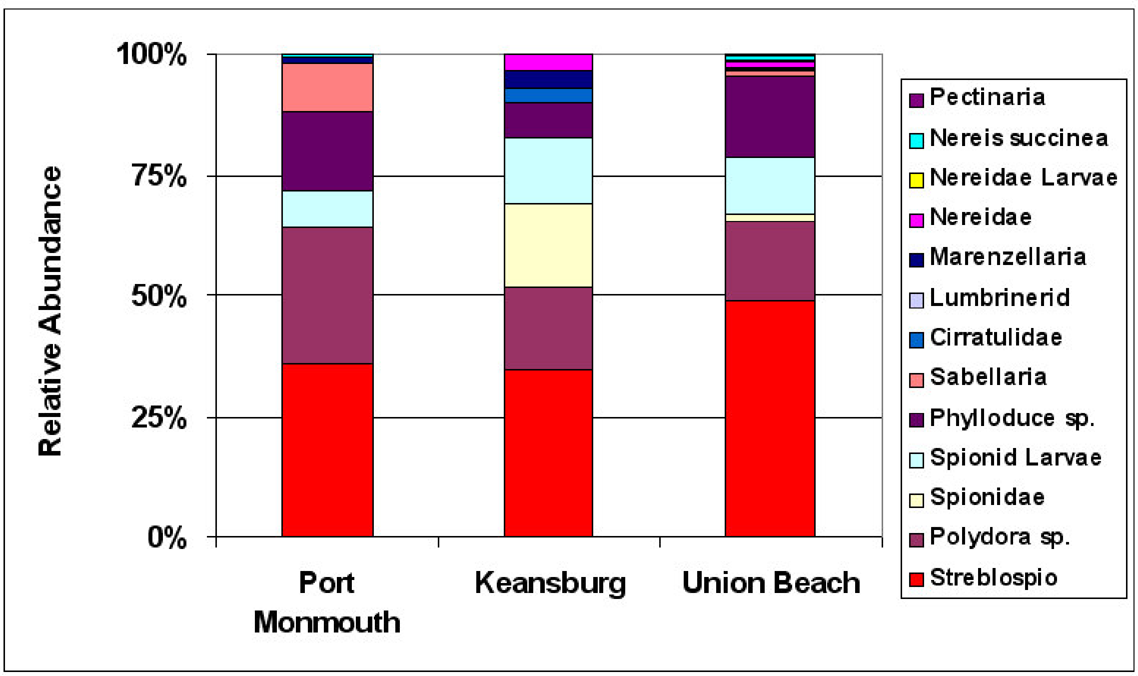


Figure 59. Relative abundance of winter flounder polychaete prey by area

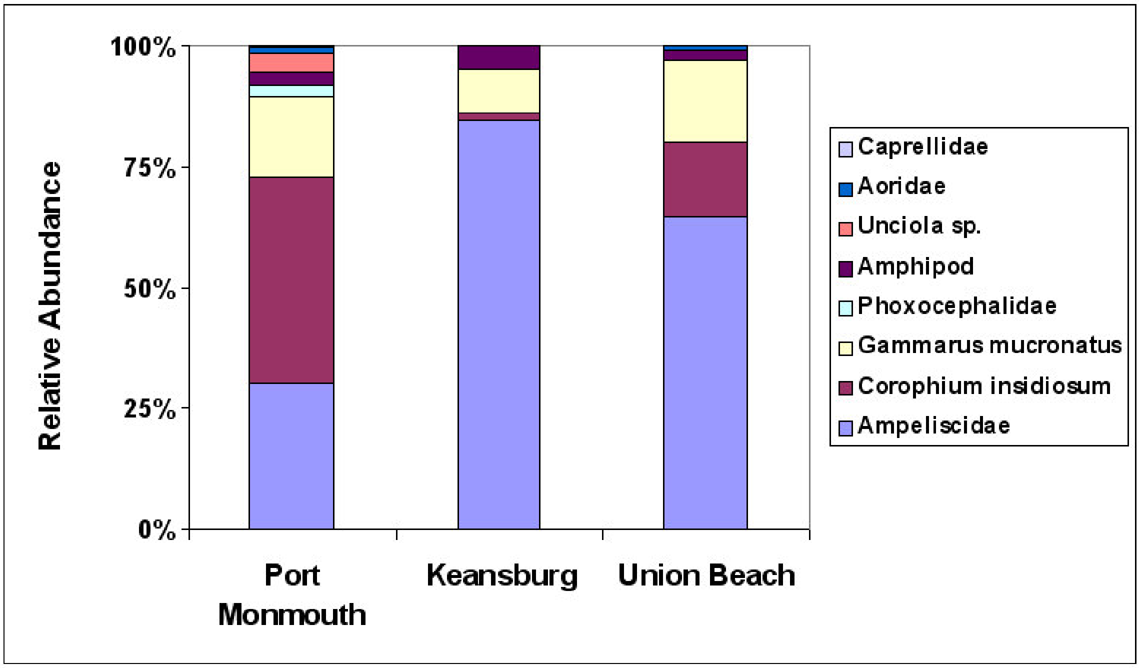


Figure 60. Relative abundance of winter flounder amphipod prey by area

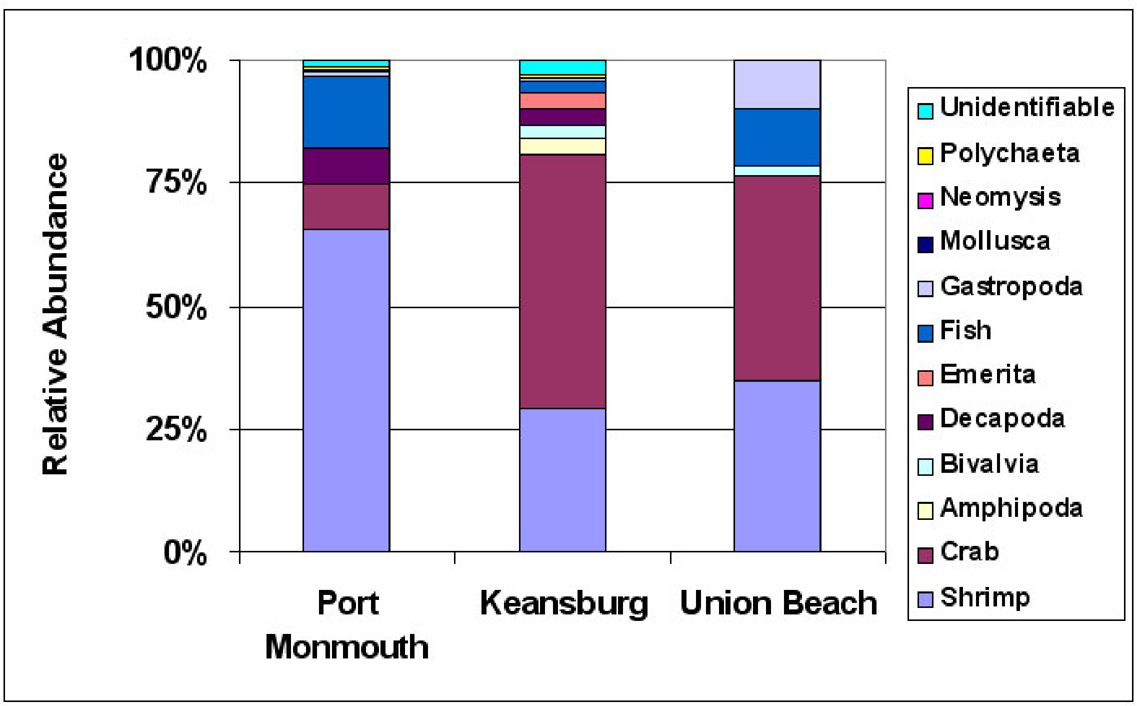


Figure 61. Relative abundance of northern kingfish prey by area

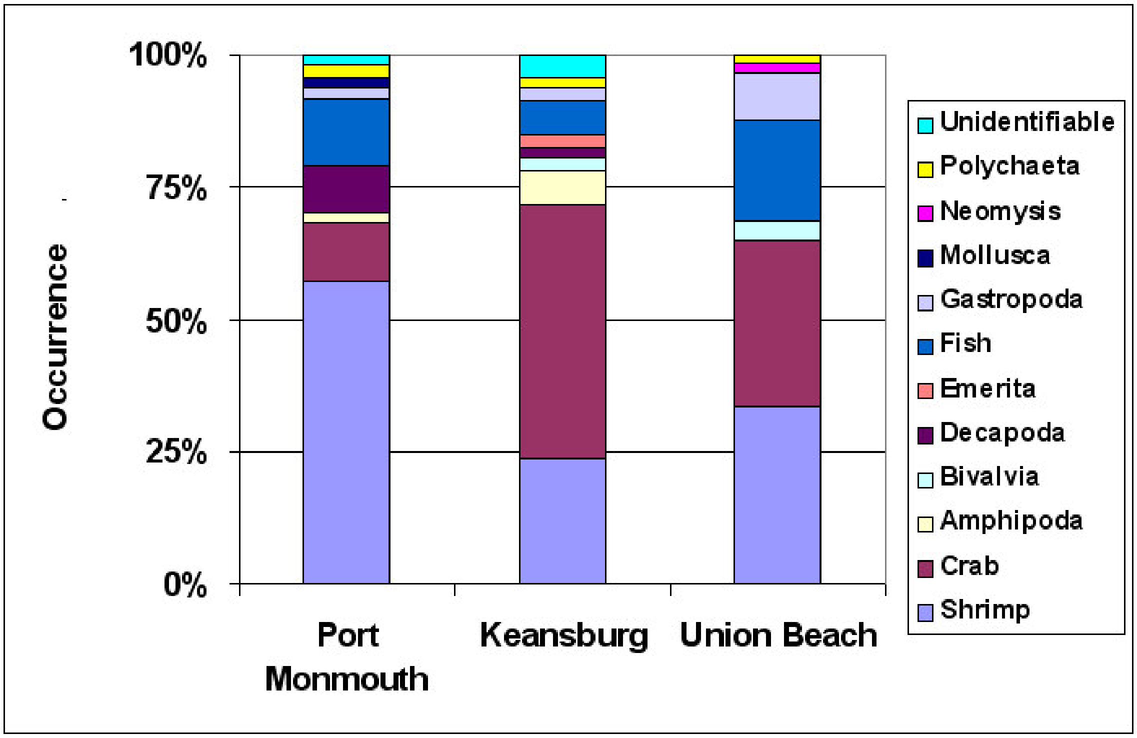


Figure 62. Occurrence of northern kingfish prey by area

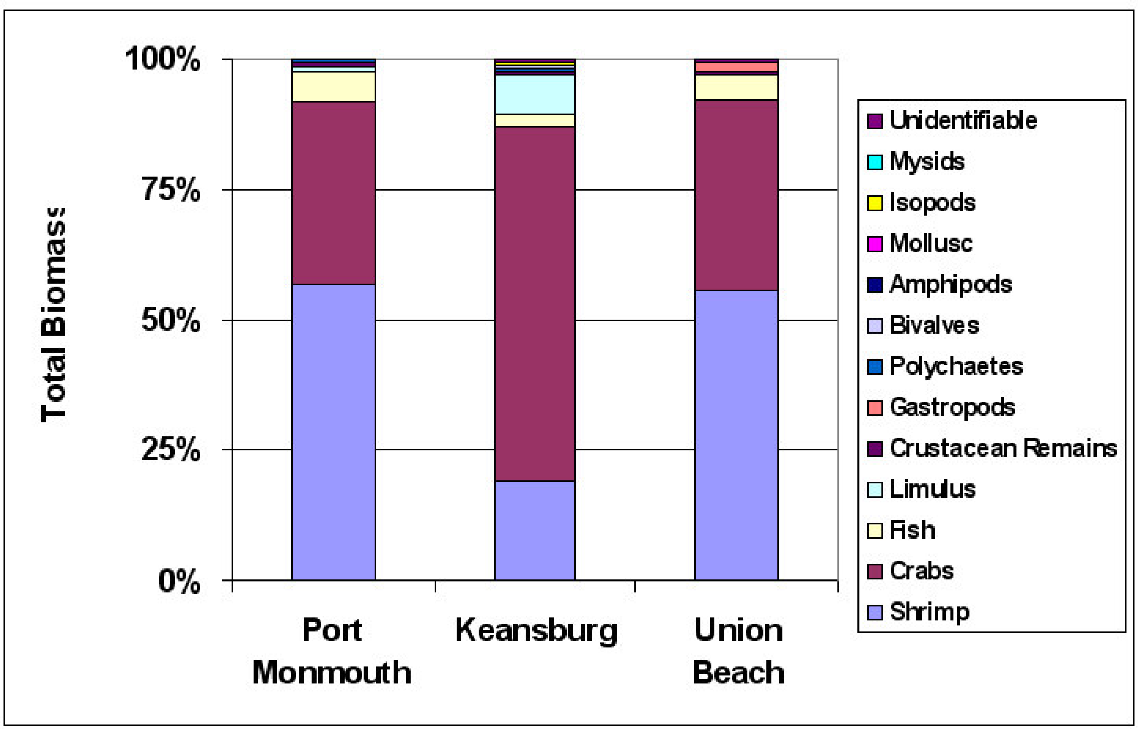


Figure 63. Biomass distribution of northern kingfish prey by area

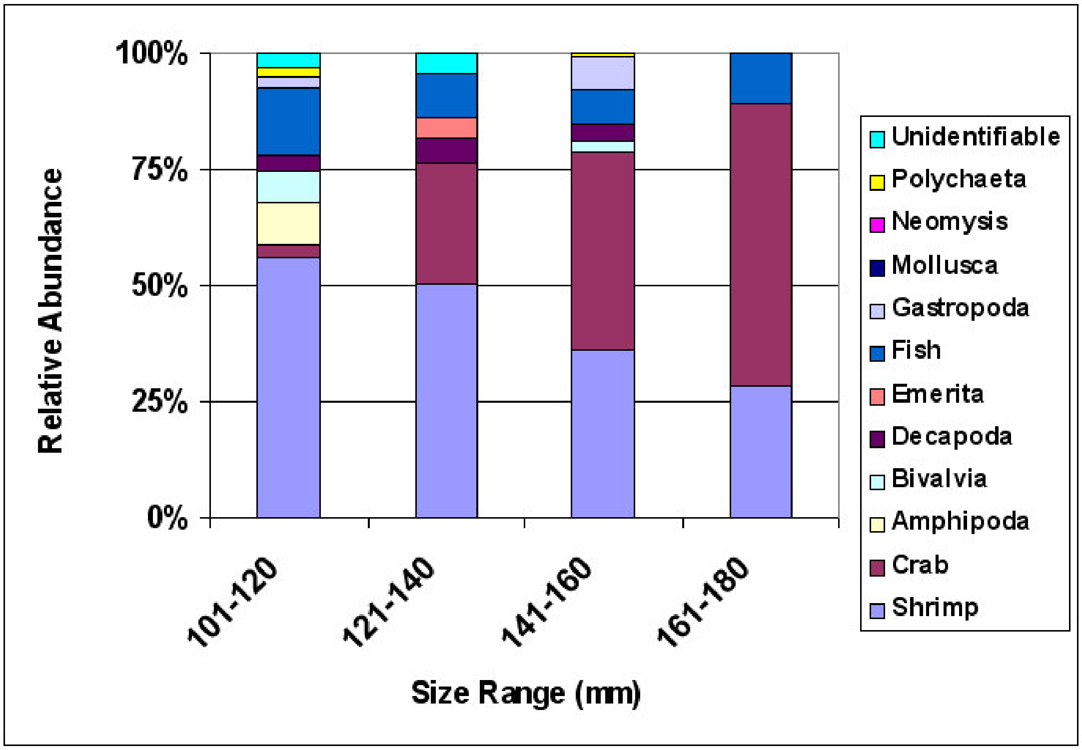


Figure 64. Relative abundance of northern kingfish prey by size

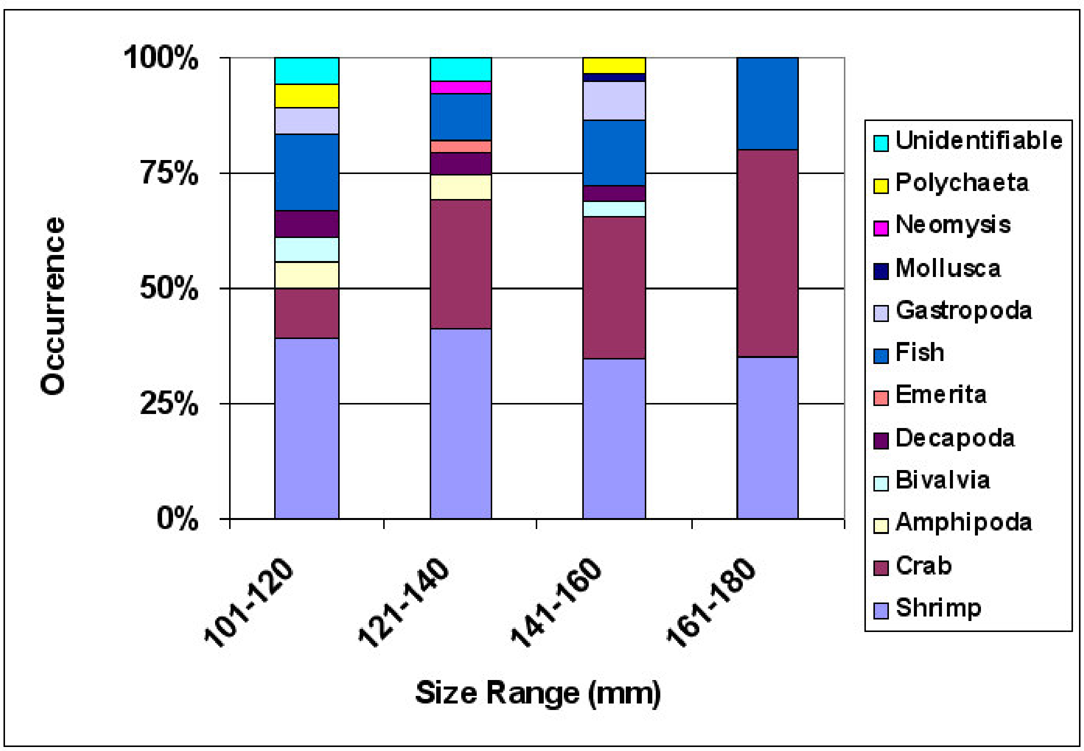


Figure 65. Occurrence of northern kingfish prey by size

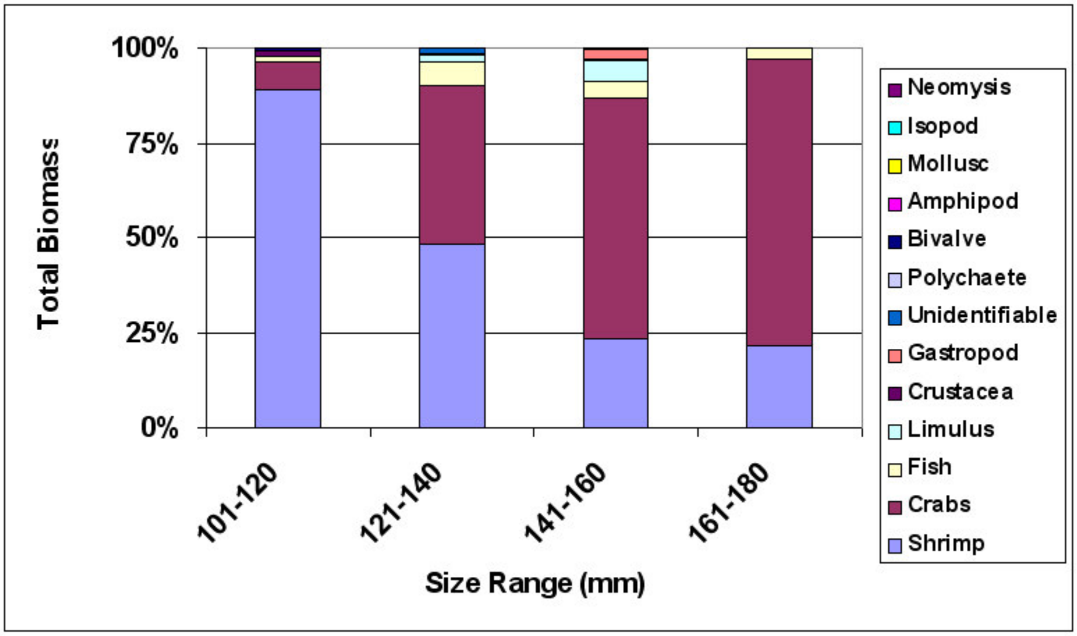


Figure 66. Biomass distribution of northern kingfish prey by size

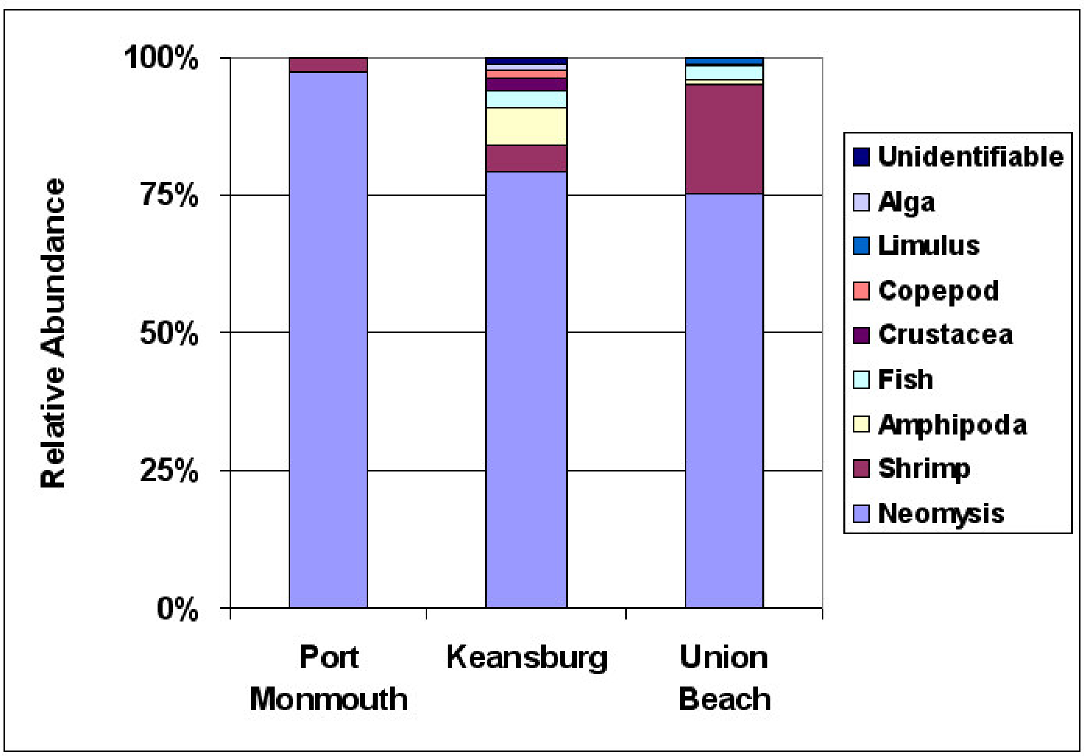


Figure 67. Relative abundance of windowpane prey by area

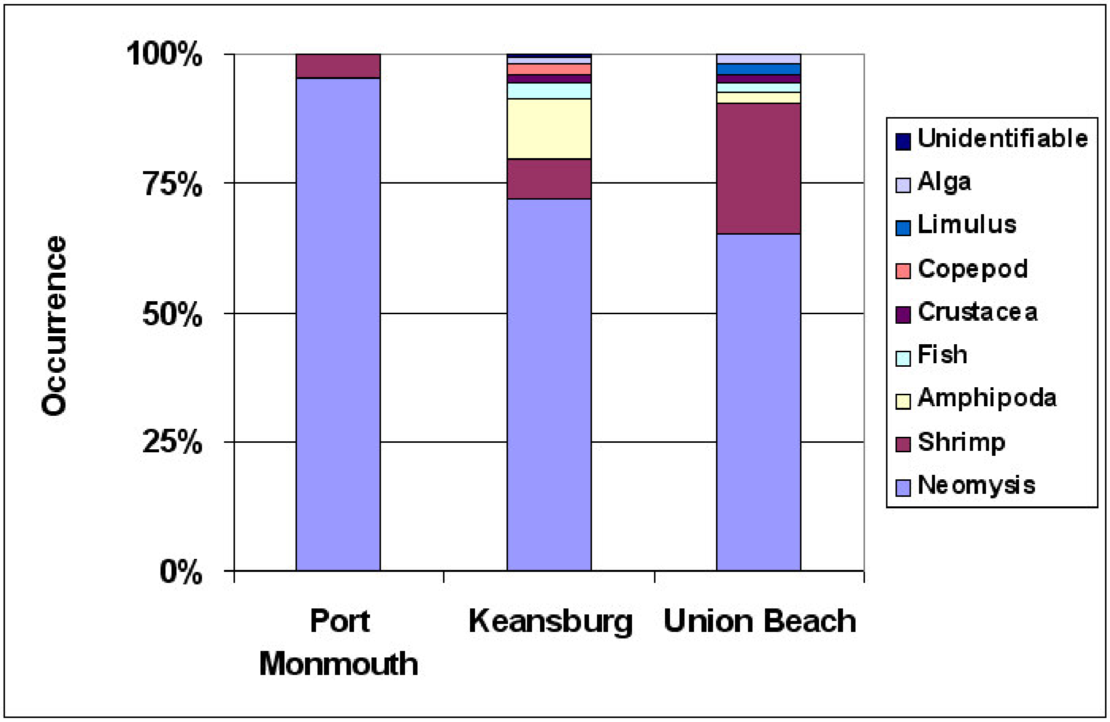


Figure 68. Occurrence of windowpane prey by area

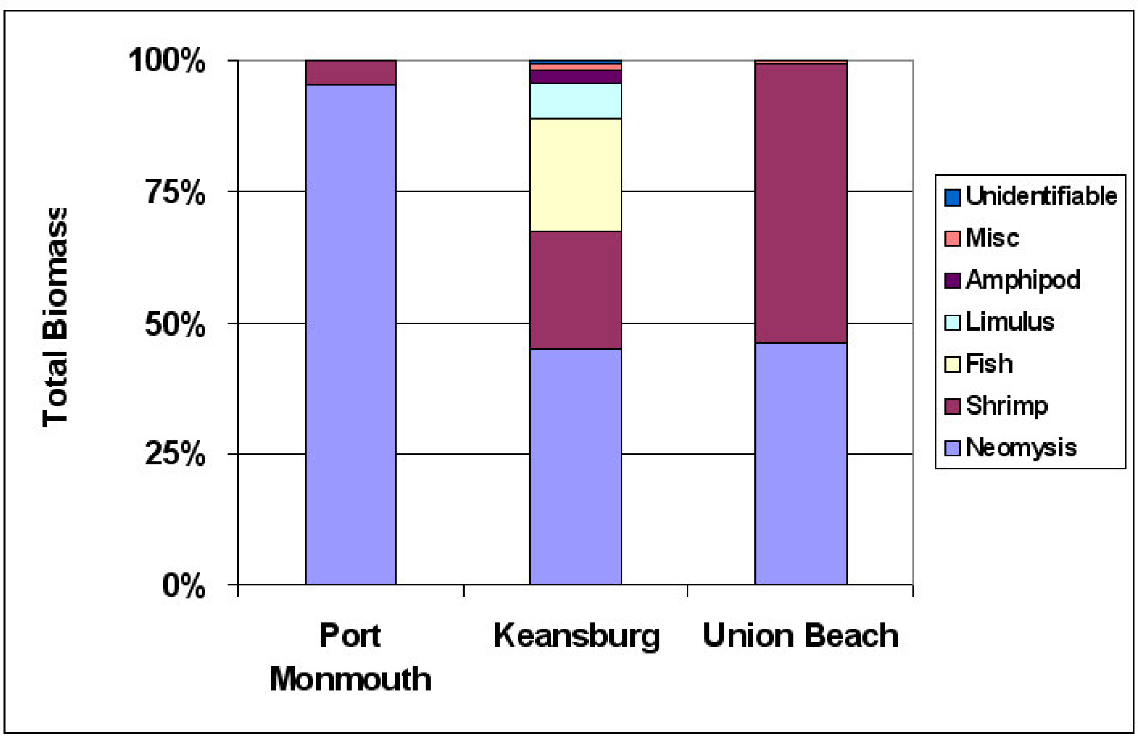


Figure 69. Biomass distribution of windowpane prey by area

Table 1. List of Finfish sites matched to benthic sites

Finfish Site	Benthic Site
UB 1	45
UB 2	46
UB 3	47
UB 4	48
UB 5	50
UB 6	51
UB 7	52

Finfish Site	Benthic Site
KB 1	21
KB 2	23
KB 3	25
KB 4	27
KB 5	29
KB 6	(PC) 41
KB 7	(PC) 43

Finfish Site	Benthic Site
PM 1	4
PM 2	5
PM 3	6
PM 4	7
PM 5	8
PM 6	9
PM 7	10

Table 2. List of fish collected and their total and relative abundances

Common Name	Scientific Name	Grand Total	%
Atlantic Silversides	*Menidia menidia*	12553	35.047
Menhaden	*Brevoortia tyrannus*	10904	30.443
Anchovy	*Anchoa spp.*	5925	16.542
Weakfish	*Cynoscion regalis*	2842	7.935
Bluefish	*Pomatomus saltatrix*	1421	3.967
Winter Flounder	*Pleuroncectes americanus*	566	1.580
Northern Pipefish	*Syngnathus fuscus*	342	0.955
Northern Kingfish	*Menticirrhus saxatilis*	274	0.765
Windowpane	*Scophthalmus aquosus*	252	0.704
Permit	*Trachinotus falcatus*	166	0.463
Cunner	*Tautogolabrus adspersus*	153	0.427
Northern Sea Robin	*Prionotus carolinus*	70	0.195
Atlantic Herring	*Clupea harengus*	54	0.151
Northern Puffer	*Sphoeroides maculatus*	44	0.123
Stargazer	*Astroscopus guttatus*	35	0.098
American Eel	*Anguilla rostrata*	34	0.095
Scup	*Stenotomus chrysops*	34	0.095
White Mullet	*Mugil curema*	31	0.087
Summer Flounder	*Paralichthys dentatus*	19	0.053
Needlefish	*Strongylura marina*	15	0.042
Striped Killifish	*Fundulus majalis*	15	0.042
Atlantic Mackerel	*Scomber scombrus*	14	0.039
Round Herring	*Etrumeus teres*	10	0.028
Mumichog	*Fundulus heteroclitus*	9	0.025
Blueback Herring	*Alosa aestivalis*	7	0.020
Lookdown	*Selene vomer*	7	0.020
Small Mouth Flounder	*Etropus microstomus*	4	0.011
Striped Bass	*Morone saxatilis*	4	0.011
Hake	*Urophycis spp.*	2	0.006
Oyster Toadfish	*Opsanus tau*	2	0.006
Spotted Hake	*Urophycis regia*	2	0.006
Tautog	*Tautoga onitis*	2	0.006
Alewife	*Alosa pseudoharengus*	1	0.003
Crevalle Jack	*Caranx hippos*	1	0.003
Gizzard Shad	*Dorosoma cepedianum*	1	0.003
Sea Horse	*Hippocampus sp.*	1	0.003
Striped Sea Robin	*Prionotus evolans*	1	0.003
White Perch	*Morone americana*	1	0.003
Grand Total		35818	

Table 3. Results of ANOVA and Tukey's HSD tests

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	23	27.587616	1.19946	5.1384
Error	143	33.380438	0.23343	Prob > F
C. Total	166	60.968054		<.0001

Effect tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Area	2	2	1.094715	2.3449	0.0995
Date	7	7	17.206272	10.5301	<.0001
Area*Date	14	14	9.283555	2.8407	0.0009

Tukey HSD test results for area and date comparisons*

					Least Sq Mean
Sept 02					
Port Monmouth	A	B	C		2.2133951
Keansburg	A				2.4653662
Union Beach	A	B			2.3428649
Oct 02					
Port Monmouth	A	B	C	D	1.6502440
Keansburg	A	B	C	D	1.8635248
Union Beach				D	1.0871093
June 03					
Port Monmouth	A	B	C	D	1.9054253
Keansburg		B	C	D	1.4817401
Union Beach	A	B	C	D	1.7418478
July 03					
Port Monmouth	A	B	C	D	1.6227952
Keansburg			C	D	1.2640177
Union Beach	A	B	C	D	1.8938937
Aug 03					
Port Monmouth	A	B			2.3680044
Keansburg	A	B	C	D	2.0037374
Union Beach	A				2.5260220
Sept 03					
Port Monmouth	A	B			2.3332086
Keansburg			C	D	1.3722873
Union Beach	A	B	C	D	2.0507074
Oct 03					
Port Monmouth	A				2.4992932
Keansburg	A	B	C		2.1724006
Union Beach	A	B	C		2.1797163
Nov 03					
Port Monmouth	A	B	C	D	1.5699504
Keansburg	A	B	C	D	1.9611147
Union Beach		B	C	D	1.4566855

*Levels not connected by same letter are significantly different

(Note: Tukey HSD Test results for date comparisons are presented in Figure 4)

Table 4. ANOSIM Results

	September 2002	
Global Test	Global R: 0.089	p level = 8.8%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.240	3.8
Port Monmouth, Union Beach	0.099	14.8
Keansburg, Union Beach	-0.081	89.2
	October 2002	
Global Test	Global R: 0.13	p level = 1.5%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.034	28.3
Port Monmouth, Union Beach	0.122	4.3
Keansburg, Union Beach	0.245	0.5
	June 2003	
Global Test	Global R: 0.164	p level = 4.4%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.190	8.0
Port Monmouth, Union Beach	0.018	31.0
Keansburg, Union Beach	0.318	1.9
	July 2003	
Global Test	Global R: 0.145	p level = 2.7%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.017	38.2
Port Monmouth, Union Beach	0.167	7.1
Keansburg, Union Beach	0.273	1.0
	August 2003	
Global Test	Global R: 0.161	p level = 3.6%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.111	14.6
Port Monmouth, Union Beach	0.206	4.6
Keansburg, Union Beach	0.161	8.2
	September 2003	
Global Test	Global R: 0.49	p level = 0.1%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.658	0.3
Port Monmouth, Union Beach	0.421	0.2
Keansburg, Union Beach	0.560	0.1
	October 2003	
Global Test	Global R: 0.272	p level = 0.5%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.004	40.6
Port Monmouth, Union Beach	0.421	0.4
Keansburg, Union Beach	0.404	0.1
	November 2003	
Global Test	Global R: 0.167	p level = 2.5%
Pairwise Tests	R	p
Port Monmouth, Keansburg	0.042	28.0
Port Monmouth, Union Beach	0.090	18.1
Keansburg, Union Beach	0.393	0.2

Table 5. Numbers of Measured* and Dissected Fish**

		Silversides	Menhaden	Anchovies	Weakfish	Bluefish	Winter Flounder
	Grand Total	4533	1519	1436	581	937	550
Area	**Port Monmouth**	1573	291	68	423	312	172
	Keansburg	1382	525	70	78	282	132
	Union Beach	1578	703	62	80	343	246
Date	**2002Sept**	1066	258	79	13	49	11
	2002Oct	580	118	53	0	388	1
	2003June	69	----	462	0	23	101
	2003July	293	114	56	0	220	90
	2003Aug	938	72	127	339	102	174
	2003Sept	346	349	300	173	33	42
	2003Oct	865	384	306	38	122	73
	2003Nov	376	224	53	10	----	58
Size Range (mm)	**21-25**	2	----	----	----	1	1
	26-30	14	16	2	----	1	18
	31-35	51	70	28	----	----	38
	36-40	44	119	28	2	1	61
	41-45	86	195	26	8	6	86
	46-50	111	223	43	24	1	87
	51-55	172	178	76	65	5	82
	56-60	214	131	167	59	29	59
	61-65	394	106	252	83	51	46
	66-70	479	71	279	55	68	27
	71-75	587	87	209	45	64	21
	76-80	549	65	118	47	88	11
	81-85	551	63	99	44	66	4
	86-90	404	53	76	50	96	2
	91-95	297	43	24	24	80	3
	96-100	208	35	3	15	77	1
	101-105	163	16	4	13	64	1
	106-110	106	20	1	8	53	1
	111-115	61	9	----	9	25	----
	116-120	26	7	----	8	19	----
	121-125	5	4	----	7	13	1
	126-130	7	1	----	3	19	----
	131-135	2	3	----	1	13	----
	136-140	----	1	----	2	33	----
	141-145	----	2	----	1	23	----
	146-150	----	1	----	2	13	----
	151-155	----	----	----	1	10	----
	156-160	----	----	----	----	8	----
	161-165	----	----	----	3	3	----
	166-170	----	----	----	----	1	----
	171-175	----	----	----	----	1	----
	176-180	----	----	----	----	3	----
	181-185	----	----	----	----	2	----
	>185	----	----	----	2	----	1

* These values represent total numbers of animals (n) measured to construct size frequency histograms and dissected for analysis of food habits.

Table 6. Average size of silversides by area and date (mm)

Date	Area	n	Mean	SE
2002Sept	Port Monmouth	374	65.0	0.7
	Keansburg	339	65.2	0.4
	Union Beach	353	66.3	0.5
2002Oct	Port Monmouth	234	75.5	0.6
	Keansburg	255	73.1	0.7
	Union Beach	91	70.7	1.8
2003June	Port Monmouth	6	99.2	6.8
	Keansburg	2	107.5	12.5
	Union Beach	61	98.4	1.6
2003July	Port Monmouth	39	52.4	2.6
	Keansburg	53	47.3	1.9
	Union Beach	201	58.4	1.6
2003Aug	Port Monmouth	329	74.5	0.4
	Keansburg	243	77.5	0.4
	Union Beach	366	77.0	0.6
2003Sept	Port Monmouth	195	78.4	0.9
	Keansburg	48	76.4	1.6
	Union Beach	103	83.4	1.1
2003Oct	Port Monmouth	241	90.1	0.6
	Keansburg	274	87.1	0.8
	Union Beach	350	85.2	0.9
2003Nov	Port Monmouth	155	102.0	0.7
	Keansburg	168	99.3	0.8
	Union Beach	53	93.0	2.7

N= number of animals, SE = standard error

Table 7. Average size of menhaden by area and date (mm)

Date	Area	n	Mean	SE
2002Sept	Port Monmouth	31	41.7	1.1
	Keansburg	138	52.3	1.2
	Union Beach	89	58.2	1.2
2002Oct	Port Monmouth	15	125.9	3.3
	Keansburg	94	56.3	0.7
	Union Beach	9	53.4	1.7
2003June	Port Monmouth	50	48.5	0.6
	Keansburg	18	40.9	1.6
	Union Beach	46	48.3	0.5
2003July	Port Monmouth	----	----	----
	Keansburg	----	----	----
	Union Beach	----	----	----
2003Aug	Port Monmouth	----	----	----
	Keansburg	6	59.7	7.5
	Union Beach	66	51.6	1.1
2003Sept	Port Monmouth	43	74.8	1.9
	Keansburg	30	46.0	2.1
	Union Beach	276	45.3	0.7
2003Oct	Port Monmouth	89	74.6	1.7
	Keansburg	133	83.5	1.4
	Union Beach	162	55.9	0.8
2003Nov	Port Monmouth	63	88.3	1.2
	Keansburg	106	82.2	2.0
	Union Beach	55	43.8	1.0

N= number of animals, SE = standard error

Table 8. Average size of anchovies by area and date (mm)

Date	Area	n	Mean	SE
2002Sept	Port Monmouth	7	40.9	2.0
	Keansburg	67	54.9	0.9
	Union Beach	5	66.0	3.3
2002Oct	Port Monmouth	1	68.0	----
	Keansburg	49	60.4	1.5
	Union Beach	3	45.0	1.7
2003June	Port Monmouth	207	69.7	0.5
	Keansburg	76	66.5	0.7
	Union Beach	179	63.1	1.0
2003July	Port Monmouth	29	73.2	1.1
	Keansburg	21	78.0	1.3
	Union Beach	6	80.3	3.6
2003Aug	Port Monmouth	27	43.2	3.0
	Keansburg	96	80.7	0.5
	Union Beach	4	39.5	2.7
2003Sept	Port Monmouth	197	67.4	0.9
	Keansburg	2	83.0	5.0
	Union Beach	107	60.3	0.9
2003Oct	Port Monmouth	206	69.5	0.8
	Keansburg	94	69.7	0.9
	Union Beach	----	----	----
2003Nov	Port Monmouth	1	67.0	----
	Keansburg	52	80.8	1.2
	Union Beach	----	----	----

N= number of animals, SE = standard error

Table 9. Average size of weakfish by area and date (mm)

Date	Area	n	Mean	SE
2002Sept	Port Monmouth	8	114.9	35.3
	Keansburg	----	----	----
	Union Beach	5	87.4	7.6
2002Oct	Port Monmouth	----	----	----
	Keansburg	----	----	----
	Union Beach	----	----	----
2003June	Port Monmouth	----	----	----
	Keansburg	----	----	----
	Union Beach	----	----	----
2003July	Port Monmouth	----	----	----
	Keansburg	----	----	----
	Union Beach	----	----	----
2003Aug	Port Monmouth	225	62.8	0.7
	Keansburg	68	66.9	1.7
	Union Beach	46	56.3	1.2
2003Sept	Port Monmouth	146	86.9	1.2
	Keansburg			
	Union Beach	27	82.6	3.2
2003Oct	Port Monmouth	36	110.3	2.5
	Keansburg	1	115.0	----
	Union Beach	1	116.0	----
2003Nov	Port Monmouth	1	120.0	----
	Keansburg	8	134.0	13.5
	Union Beach	1	123.0	----

N= number of animals, SE = standard error

Table 10. Average size of bluefish by area and date (mm)

Date	Area	N	Mean	SE
2002Sept	Port Monmouth	15	77.1	2.3
	Keansburg	201	80.4	0.8
	Union Beach	172	81.5	1.0
2002Oct	Port Monmouth	36	139.4	2.7
	Keansburg	13	133.2	2.7
	Union Beach	----	----	----
2003June	Port Monmouth	17	79.7	1.8
	Keansburg	6	73.2	5.1
	Union Beach	----	----	----
2003July	Port Monmouth	99	98.7	1.1
	Keansburg	68	107.9	1.0
	Union Beach	53	107.1	1.4
2003Aug	Port Monmouth	25	137.8	5.7
	Keansburg	21	147.1	2.5
	Union Beach	56	136.3	2.8
2003Sept	Port Monmouth	31	129.7	5.7
	Keansburg	----	----	----
	Union Beach	----	----	----
2003Oct	Port Monmouth	120	97.4	1.4
	Keansburg	----	----	
	Union Beach	----	----	----

N= number of animals, SE = standard error

Table 11. Average size of winter flounder by area and date (mm)

Date	Area	n	Mean	SE
2002Sept	Port Monmouth	7	96.6	36.1
	Keansburg	1	53.0	----
	Union Beach	3	65.3	2.6
2002Oct	Port Monmouth	1	92.0	----
	Keansburg	----	----	----
	Union Beach	----	----	----
2003June	Port Monmouth	37	39.4	2.0
	Keansburg	39	33.8	0.8
	Union Beach	25	35.5	0.9
2003July	Port Monmouth	28	44.3	0.9
	Keansburg	14	45.6	1.3
	Union Beach	48	48.5	0.9
2003Aug	Port Monmouth	62	49.6	0.9
	Keansburg	70	49.3	1.0
	Union Beach	42	47.9	1.0
2003Sept	Port Monmouth	11	63.4	1.9
	Keansburg	4	63.0	6.9
	Union Beach	27	57.7	0.8
2003Oct	Port Monmouth	16	66.5	3.5
	Keansburg	3	80.3	13.6
	Union Beach	54	62.0	1.5
2003Nov	Port Monmouth	10	65.5	3.0
	Keansburg	1	91.0	----
	Union Beach	47	64.5	1.2

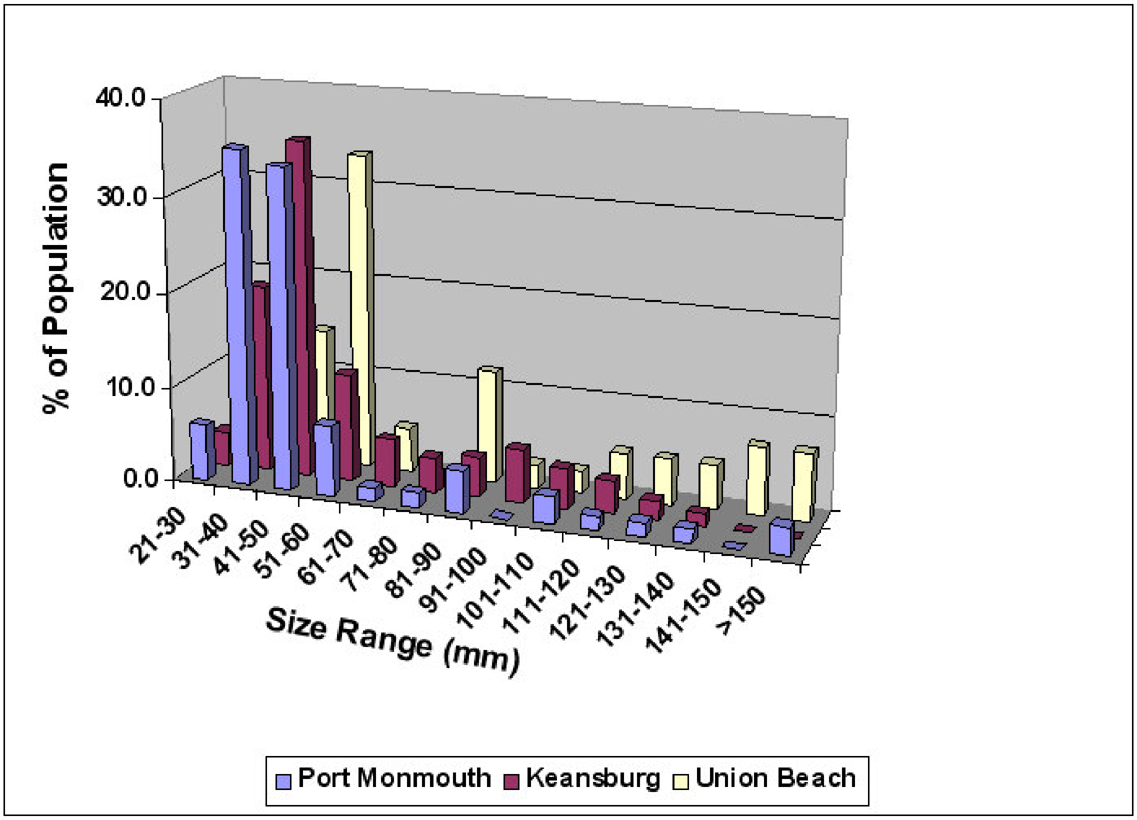
N= number of animals, SE = standard error

Table 12. Comparison of fish taxa collected from different studies in Raritan Bay and Lower New York Harbor

Taxon	This Study	Wilk et al. 1977	Wilk et al. 1996
Alewife	<1	3.8	2.1
American Eel	<1	----	<1
Anchovy	16.5	58.0	33
Atlantic Herring	<1	<1	2.2
Atlantic Mackrel	<1	----	----
Blueback Herring	<1	7.4	1.9
Bluefish	4.0	1.0	<1
Crevalle Jack	<1	----	<1
Cunner	<1	<1	<1
Gizzard Shad	<1	----	<1
Hake	<1	----	
Lookdown	<1	----	<1
Menhaden	30.4	2.0	<1
Mumichog	<1	----	----
Northern Kingfish	<1	<1	<1
Northern Pipefish	1.0	<1	<1
Northern Puffer	<1	----	<1
Needlefish	<1	----	----
Northern Sea Robin	<1	<1	3.1
Oyster Toadfish	<1	----	<1
Permit	<1	----	----
Round Herring	<1	----	----
Scup	<1	<1	11.6
Sea Horse	<1	<1	<1
Silversides	35.0	1.1	<1
Small Mouth Flounder	<1	----	<1
Spotted Hake	<1	<1	4.3
Stargazer	<1	<1	<1
Striped Bass	<1	----	<1
Striped Killifish	<1	----	----
Striped Sea Robin	<1	<1	5
Southern Flounder	<1	1.0	2.1
Tautog	<1	<1	<1
Winter Flounder	1.6	4.1	16.8
Weakfish	7.9	1.8	1.2
White Mullet	<1	<1	----
White Perch	<1	----	----
Windowpane	0.7	1.5	13.7
Butterfish	----	1.3	18.7
Red Hake	----	3.1	2.4
Silver Hake	----	1.1	1.1
White Hake	----	<1	----
Sand Lance	----	<1	----
Skates	----	<1	1.3

Table 13. Dominant Prey items for Selected Fish Species. (Percent relative abundance; + indicates <1% of total abundance)

Prey Item	Silversides	Bluefish	Weakfish	Winter Flounder	Northern Kingfish	Windowpane
Unidentifiable	20.80	4.57	1.20	1.98	1.41	
Amphipod remains	13.65	+	2.03	+		
Limulus larvae	12.85		3.61			+
Neomysis americana	8.49	29.97	+	3.80	+	78.97
Limulus Eggs	6.15			+		
Fish Scales	5.18	2.71	5.58	+	1.50	+
Fish	4.48	45.65	20.52		7.91	1.08
Ampelisca abdita	4.01		3.57	19.27	1.12	2.35
Crustacean remains	3.65	+		+		1.22
Copepoda	3.55			+		+
Mysid remains	3.20	3.97	+			5.32
Insect remains	3.16					
Corophium sp.	2.63		+			+
Diatoms	2.56					
Ulva sp.	1.77					
Polychaete remians	1.21	+		15.59	+	
Flying ants	1.19					
Crangon septemsinosus	+	9.58	53.76	+	28.94	3.41
Shrimp remains	+	1.48	1.30	+		
Palaemonetes pugio	+	1.40	5.29		12.91	4.01
Streblospio benedicti				15.44		
Polydora sp.				3.97		
Crab Megalops	+		+	3.66		
Sabellaria vulgaris	+			3.51		
Bivalve Siphons				3.32	1.79	
Gammarus mucronatus				3.14		+
Phylloducidae				3.06		
Spionidae				2.70		
Spionid Larvae				2.08		
Gemma gemma	+			1.88		
Gastropod siphons				1.76	3.26	
Edotea triloba	+			1.52		
Spionid Palps				1.07		
Gammarus (LPIL)	+			0.97	+	
Decapod remains	+			+	29.63	
Pagurus sp.	+			+	5.02	
Portunidae					1.01	
Xanthidae			+		2.86	
Emerita talpoida	+				1.12	



Appendix Figure 1. Size Distribution of windowpane by area.